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RESEARCH ON THE APPLICATION OF ROLLER COMPACTED CONCRETE CONTAINING RECLAIMED ASPHALT PAVEMENT IN CONSTRUCTION OF HIGHWAY PAVEMENT IN VIET NAM

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INTRODUCTION

I. RESEARCH BACKGROUND

The socio-economic development, the rapid increase of means of transport, especially the heavy trucks, make the quality of the road surface deteriorate, causing damage to the pavement structure, especially the asphalt pavement. Damaged asphalt pavements are scraped and turned into non-biodegradable waste materials. Therefore, in order to limit environmental pollution and reuse of waste materials, many countries around the world have applied asphalt pavement recycling technologies. These technologies allow the pavement to be repaired and reinforced with old asphalt concrete materials, reducing contruction costs, reducing construction time compared to conventional technologies, having a good impact on the environment, and limiting the amount of waste emissions from mixing plants during the construction of new roads. Recently, some countries such as the US, France, Belgium, Germany,... have applied cold recycling asphalt pavement in mixing plants which using reclaimed asphalt pavement (RAP) to replace part of natural aggregates to make roller compacted concrete for foundation, low-grade pavement, sidewalks, parking lots, ...is very effective.

In Vietnam, in the past few years, the Ministry of Transport has become interested in asphalt pavement recycling technologies such as: cold-in-place recycling asphalt pavement with foam bitumen and cement or with improved asphalt emulsion; hot recycling asphalt pavement technologies, warm asphalt pavement recycling technologies,... to ensure economic, environmental and social requirements. However, the application of asphalt pavement recycling technologies is not widespread, so it is not possible to recycle all the increasing amount of RAP. In addition, the cold recycling asphalt pavement in mixing plants to produce roller compacted concrete has not been applied in the construction of highway pavement. Therefore, the thesis is researched with the title***: "Research on application of roller compacted concrete containing reclaimed asphalt pavement in construction of highway pavement in Vietnam"*** is necessary.

II. RESEARCH OBJECTIVE

The basis for using reclaimed asphalt pavement to replace natural aggregates to make roller compacted concrete (RCC) reduced the construction costs and environmental pollution, saved natural materials. At the same time, research the application of roller compacted concrete containing reclaimed asphalt pavement in the construction of highway pavement in Vietnam.

III. RESEARCH SCOPE

- Research on technology of roller compacted concrete using reclaimed asphalt pavement applied as foundation layer, low-grade surface layer, car parking, ... in Vietnam.
- Select materials, the amount of RAP, the amount of cementitious materials to design the model of mix for RCC RAP, determination of some basic mechanical properties of RCC RAP in the laboratory, application of laboratory experimental results to build the experimental RCC RAP pavement. On that basis, propose some pavement structures in the construction of highway pavement in Vietnam.

IV. RESEARCH METHODOLODY

Combine between theoretical, experimental method and field experiment.

V. SCIENTIFIC AND PRACTICAL CONTRIBUTION

- **Scientific contribution:** The research results of the thesis is useful references on the method of designing RCC RAP, the basis for selecting the amount of RAP, the amount of cementious materials used in RCC RAP. Propose some pavement structures of RCC RAP in the construction of highway pavement in Vietnam.

- Practical contribution: The research results contribute to the introduction of cold asphalt pavement recycling technologies in mixing plants, which is RCC RAP, save natural materials, reducing construction costs, protect the environment, use the construction waste materials.

VI. SCIENTIFIC AND PRACTICAL CONTRIBUTION

The thesis includes: Introduction, 4 main chapters, conclusions, recommendations and research orientation, references and appendix.

CHAPER 1. LITERATURE REVIEW

The purpose of this chapter is to study the technology of roller compacted concrete used in construction of highway pavement. Research on reclaimed asphalt pavement such as mechanical properties, production process, recycling asphalt pavement technologies. From there, evaluate the effectiveness of using a part of RAP to make RCC RAP. Propose the research orientation of RCC RAP in construction of highway pavement in Viet Nam.

1.1. Roller compacted concrete

Roller compacted concrete is a type of cement concrete without slump, which is tightened by compaction equipment from the outside (vibrating roller). This technology is suitable for large cement concrete, unreinforced such as dams and highway pavements. The use of a drier concrete (no slump concrete) and compaction by vibrating rollers makes construction faster and cheaper than using traditional cement concrete.

1.1.1. Review of research and application of roller compact concrete in the world and in Viet Nam

1.1.1.1. In the world

In 1942, the first roller compacted concrete pavement in North America was designed by the American Association of Army Engineers. Since then, roller compacted concrete pavement has been used in many countries around the world such as the US, Canada, Japan, France,...Thus, roller compacted concrete applied in construction of highway pavement has advantages such as: uncomplicated construction techlonogy, lower cement content, can be used some by-products or industrial waste helps to lower the cost of materials compared to normal cement concrete, faster construction speed.

1.1.1.2. In Viet Nam

At the end of 1995, for the first time, roller compacted concrete was studied in an irrigation project in Vietnam. In 2001, the technology of roller compacted concrete pavement was also studied and tested in Vietnam with about 2,000 m^2 in Bac Ninh town (thickness 20 cm, grade 35/45). In 2013, a group of research authors applied roller compacted concrete pavement for construction of rural roads in Tay Ninh province. The results obtained from the application of this technology had brought very positive results. In 2015, the 300 m of the road in Cam Xuyen, Ha Tinh was built by roller compacted concrete pavement.

1.1.2. Introduction

1.1.2.1. Materials

- Cement: use Portland cement or mixed Portland cement.

- Aggregates: includes coarse aggregate and fine aggregate.

- Water: clean water according to TCVN 4506: 2012.

- Admixtures: used additives: plasticizers-water-reducing, water-reducing and prolonging setting time.

1.1.2.2. Engineering properties

- Strength: is the most important propertie and is usually evaluated by two strengths: flexural strength and compressive strength.

- Modulus of elasticity: characterizes the ability of concrete to deform under the action of loads. The modulus of elasticity depends on the strength of coarse aggregate.

- Shrinkage: After surface construction and finishing, roller compacted concrete pavement often cracks in the early days due to shrinkage, continuous wet-dry transition during curing and due to limitations by the friction between the slab bottom and the foundation.

- Permeability: depends on the porosities compacted, the porosity of the aggregates, so the permeability is controlled by the ratio of the aggregate mixture, the construction techlonogy and the compaction density.

- Abrasion: depends on 2 elements: the compressive strength of the concrete, the strength of the coarse.

1.1.2.3. Construction technology of roller compacted concrete pavement

- In 2015, the Ministry of Transport issued No.4452/QD-BGTVT "Guide for construction techniques and acceptance test of RCC pavement in the construction of highway pavement".
- In 2019, the Ministry of Construction issued the technical guide "Roller-compacted concrete pavement using fly ash".

1.2. Reclaimed asphalt pavement

Damaged asphalt pavement is scraped by machine, the reclaimed asphalt pavement becomes non-biodegradable waste material, causing environmental pollution if not reused (Figure 1-6).

a. Scratch asphalt concrete pavement b. Reclaimed asphalt pavement

Figure 1-6. Scratch off damaged asphalt concrete pavement and Reclaimed asphalt pavement

1.2.1. Review of research and application of RAP in the world and in Viet Nam

1.2.1.1. In the world

Since 1915, the use of Reclaimed Asphalt Pavement (RAP) had been mentioned. According to statistics of the European Asphalt Association, about 80-90% of reclaimed asphalt pavement was recycled out of the total asphalt pavement in Germany, the US, France, Belgium, the Netherlands, and Luxembourg; 50 – 60% RAP in China, Slovenia, Sweden, Switzerland and Denmark. Currently, there were many recycling asphalt pavement in mixing plants technologies in Europe and Japan that allow recycling with 100% RAP.

According to researches and applications in the world, the use of a certain amount of RAP will change the mechanical properties of the concrete. Recycled concrete mix had good waterproofing ability, increasing stiffness and increasing crack resistance for the concrete. When analyzing the construction costs of pavements using RAP, it was found that $58,000/km can be saved when using 30% - 50% RAP, reduced 30% of the construction cost due to saving part of bitumen, transportation costs, part of the cost of buying new natural aggregates. At the same time, in a research in the US, it had been shown that the use of 15% RAP or more could reduce the amount of heat generated, reduced climate change and the use of natural aggregates from 13% - 14%. With economic efficiency and environmental friendliness, the asphalt pavement recycling technologies were used as a reasonable choice in construction of highway pavement.

1.2.1.2. In Viet Nam

In 2012, the Ministry of Transport decided to apply asphalt pavement recycling technologies to upgrade and repair the asphalt pavements. Through the initial testing period, they were shown economic

efficiency and especially environmental protection, which could be widely applied to highway pavement that need to be renovated and upgraded. Currently, many companies continue to research asphalt pavement recycling technologies to suit the conditions in Vietnam, in which BMT company had achieved a step forward in the process of recycling asphalt pavement in mixing plants. From the design of the original recycled asphalt mix of about 5% and 10%, the company had developed the process of recycling asphalt pavement in mixing plants with a higher level than 50%. Many experimental results shown that the quality of recycled asphalt concrete is similar to that of traditional asphalt concrete.

1.2.2. Asphalt pavement recycling technologies

1.2.2.1. In-place recycling asphalt pavement

Includes the following two technologies:

- Hot-In-Place Recycling asphalt pavement (HIR).
- Cold-In-Place Recycling asphalt pavement (CIR).

1.2.2.2. Recycling asphalt pavement in mixing plants

Includes the following three technologies:

- Hot recycling asphalt pavement in mixing plants
- Cold recycling asphalt pavement in mixing plants
- Warm recycling asphalt pavement in mixing plants

1.2.3. Processing and stockpiling of RAP

1.2.3.1. Processing of RAP

The depth of RAP is determined through the propagation length of the cracks of the drilled samples, the thickness of the destroyed asphalt layer or the degree of adhesion between two layers of asphalt concrete.

1.2.3.2. Crushing, screening and stockpiling of RAP

- Crushing and screening: In order to remove oversized particles and separate into different particle sizes, at least 95% of the particles pass through the 50 mm sieve. Most contractors grind recycled aggregate to particle sizes with Dmax = 12,5 mm or Dmax = 19 mm. Grading of grain sizes during grinding can control the content of particles less than 0.075 mm.

- Stockpiling: After crushing and screening, the aggregate is moved to a convenient location to be put into the batching plant, then stored, stored or used immediately. The best way to limit moisture in recycled aggregate is to build a shelter with a roof, placed on a high, well-drained platform.

1.2.3.3. Laboratory testing

Mechanical properties of RAP include: the old asphalt binder of RAP, gradation of RAP after crushing and screening, density, compressive strength, ...

1.2.4. Properties of RAP and RAP blends

1.2.4.1. Gradation

After grinding, tradation of RAP will be different from the original scraped aggregate because during the crushing and screening process, the scraped aggregate may be broken, changing the particle size, thereby changing the particle composition compared to the original scraped aggregate. with the original.

1.2.4.2 Density and moisture content

The density can vary from 115 to 130% depending on the source of RAP. In addition, due to the asphalt coating on the surface of the aggregate, the density of RAP will increase significantly. The moisture content of the RAP when tested was lower than that of natural aggregates.

1.2.4.3. Permeability

The permeability of RAP after crushing and sieving is higher than that of the natural aggregate.

1.2.4.4. Durability and bear capacity

The strength of RAP depends on the strength of the natural aggregate used in the initial asphalt mix.

1.2.4.5. Permanent deformation

The strain increases as the percentage of RAP increases. With the mixture using 100% RAP, the deformation reached the maximum value.

1.2.4.6. Properties of old asphalt binder

The increase in stiffness of old asphalt can increase the deformation and load propagation capacity in the concrete.

1.3. Review of roller compacted concrete containing coarse reclaimed asphalt pavemnt

1.3.1. Review of research on application in the world and in Viet Nam

1.3.1.1. Research on the morphological features of the cement mortar and the old asphalt binder in RCC RAP

Research by authors Solomon Debbarma and Ransinchung R.N GN presents the mechanism of interaction between cement mortar and old asphalt binder in RCC RAP. The test was carried out on roller compacted concrete containing 50% RAP. The mechanism of interaction between aggregate and cement mortar of roller compacted concrete is similar to that of normal cement concrete. However, due to the use of recycled aggregates to partially replace natural aggregates, in the RCC RAP, two transition zones (ITZ) appear: ITZ between natural aggregate and cement mortar and ITZ between RAP and cement mortar.

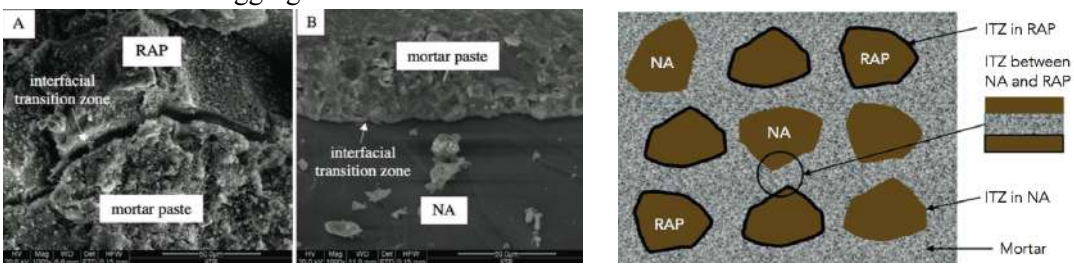


Figure 1-19. ITZ between RAP (A) và natural aggregate (B) với cement in RCC-50%RAP

The experimental results show that, when using RAP instead of natural aggregate, the strength of roller compacted concrete is reduced, even when fly ash is added. The presence of a hydrophobic asphalt layer covering the aggregate limited the formation of a good transition zone (ITZ) between RAP and the cement mortar, as a result, the strength of the roller compacted concrete was reduced. Cracks propagate around the surface of RAP, not through the aggregate as in the case of concrete using natural aggregates.

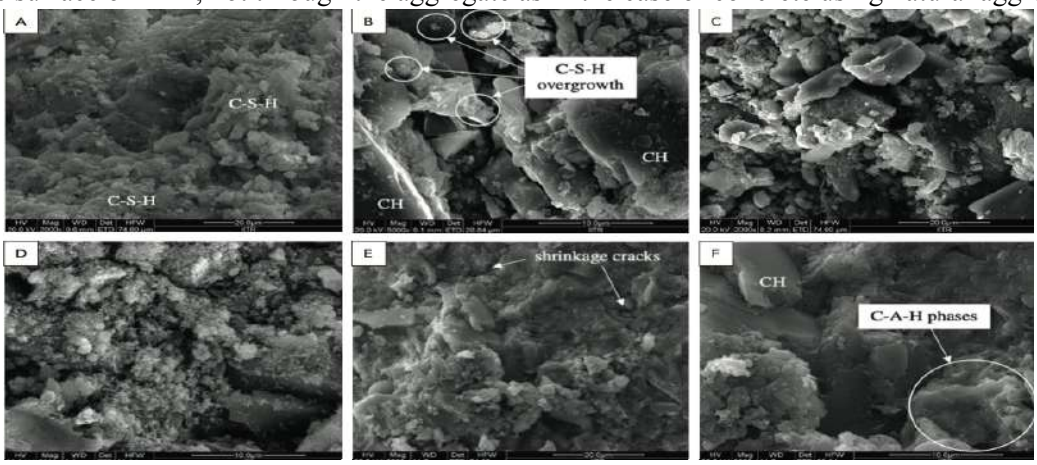


Figure 1-20. SEM micrographs of RCC – 50 %RAP

Observe the SEM, ITZ between RAP and cement mortar is more porous than ITZ between natural aggregate and cement mortar. The reason is that the C-S-H content in ITZ of RAP – cement mortar is lower

than that of ITZ of natural aggregate – cement mortar. The ITZ transition zone with asphalt layer is the first area where the failure of the RCC RAP occurs because this area is more porous and has higher porosity. The authors conclude that this is the main reason for the decrease in strength and elastic modulus of RCC RAP. Adding fly ash to the mixture contributes to improving the porosity in the mixture, increasing the density, thereby increasing the strength of the RCC RAP.

1.3.1.2. Research on the mechanical properties of RCC RAP

Researches in the world have shown that RAP was different from natural aggregates because of the old asphalt layer, so the moisture and water absorption capacity of RCC RAP is lower than that of the control roller compacted concrete. At the same time, the compressive strength, tensile and flexural strength (splitting strength), and elastic modulus of RCC RAP were reduced compared to the control roller compacted concrete. However, the mechanical properties of RCC RAP still were complied the standards. So, the use of RAP is very effective, saving resources of natural materials, it is possible to RCC RAP layer as the foundation layer, sidewalks, car parking,... On the other hand, when using the steel fibre-reinforced roller-compacted concrete (FRCCTM) technique, the addition of steel fibers allown minimising crack width.

1.3.2. Review of research on application

Although RCC RAP is quite new techlonogy and has not been applied in the construction of highway pavement in Viet Nam, but the application of this technology is very promising and effective in foundation layer, sidewalks, car parking,...

1.4. Problem statement

The thesis "Research on application of roller compacted concrete containing reclaimed asphalt pavement in construction of highway pavement in Viet Nam" focused on the following issues:

- Research on using RAP to replace part of natural aggregates to make RCC RAP in the construction of highway pavement in Viet Nam.
- Research on design method of RCC RAP using two types of RAP (RAP1 and RAP2) with two amounts of RAP (40% and 80%), two types of cement (PC40 and PCB30) with three amounts of cementious materials (10%, 13% and 15%), the effect of old asphalt binders wrapping around RAP.
- Research and evaluate some main technical properties of roller compacted concrete containing reclaimed asphalt pavement from laboratory experimental study and field results.
- Research and propose some pavement structures of RCC RAP in Viet Nam.
- Evalute the applicability of cold recycling asphalt pavement technology of RCC RAP in the construction of highway pavement in Vietnam.

CHAPTER 2. RESEARCH FOR SELECTION OF METHOD AND CALCULATE THE MODEL OF MIX DESIGN FOR ROLLER COMPACTED CONCRETE CONTAINING RECLAIMED ASPHALT PAVEMENT

The model of mix design for RCC is the study of theoretical calculations, then conducting the laboratory experimental study, thereby selecting a reasonable proportion of the fabricated material components. So, the selection of a method for designing the composition of RCC is an important step to ensure the quality of the cement concrete, in accordance with the actual construction technology and type of structure, and to ensure the quality of the concrete economicity. In this chapter, present these methods of proportion RCC pavement mixtures in the world, analysis, select the method for mix design and calculate the composition of RCC RAP according to current standards.

2.1.3. Research and selecting of the method of mix design for RCC RAP

2.1.3.1. General

- Control the maximum diameter of coarses, the ratio between the aggregate particles is reasonable.
- In the design of the aggregate mixture, the addition of admixtures is considered.
- Consider RCC as soil (from the proportioning by soil compaction methods) determining the optimal amount of water and relation between W/C.
- When calculation of design mixture, ensure that the RCC must be satisfied the requirements of strength and durability and limit the increase of heat in concrete.
- Before putting the constructive mixture, it is often necessary to go through the the laboratory experimental study to evaluate the technical properties to check, thereby deciding the composition of the mixture.

2.1.2. Research methods of design mixture proportioning

- Follow the principle of traditional cement concrete.
- Parameters of RCC include: water content and ratio of cementious materials to water, ratio of aggregates mixture to binder, relationship between sand and aggregate mixture, relationship between the cementitious mortar and sand content.

2.1.3. The methods of design mixture proportioning of RCC pavement

2.1.3.1. Proportioning by evaluation of consistency tests

The method of design mixture proportioning of RCC pavement according to principle of the traditional cement concrete. The method of design mixture proportioning of the traditional cement concrete is considered the filling, mutual compaction between materiels in concrete as the basis for the calculation. This method is widely used to design dams, spillways, ...

Some methods:

- Residual method – US Bureau of Reclamation (USBR)
- Design mixture proportioning of RCC pavement - American Concrete Association
- RCCD method – China

2.1.3.2. Proportioning by soil compaction methods

This method is based on the relationship between water content and compaction. With a compaction force, it could be found an "optimal water content". Based on this optimum water content, the maximum dry volumetric weight was found. This method is widely used to design mixture proportioning of RCC in construction of highway pavement.

Some methods:

- Design mixture proportioning of RCC components according to ACI 325.

2.1.3.3. Relationship

- In common: according to theoretical studies, two methods are designed to design concrete without slump and to find the optimal water content. At the same time, it is easy construction, achieves the required tightness and has a long service life.
- Differences:

+ Proportioning by evaluation of consistency tests: shows the properties of filling by cement mortar and aggregates mixture to have the smallest porosity. The mixture proportioning of RCC pavement is based on the relationship between compressive strength and some other properties. The compressive strength and the vebe are the design parameters.

+ Proportioning by soil compaction methods: is established based on the relationship between the optimum moisture content and the maximum dry density of the mixture with different moistures, thereby finding the the optimal water content. The optimum moisture content and the maximum dry density of the mixture are the design parameters.

2.1.4. Analysis and selection of the methods of design mixture proportioning of RCC RAP pavement

With proportioning by evaluation of consistency tests, compressive strength and other properties of RCC were followed the relationship between W/C established by Abrams. Those formulas were based on studies using natural aggregates and experimental coefficients that depended on the properties of natural aggregates (natural aggregates must be clean and solid). Therefore, when using RAP to design RCC, outside of RAP is wrapped by an old asphalt layer, so when using experimental formulas of proportioning by evaluation of consistency tests to calculate is not accurate and reasonable, the calculation results do not reflect the properties of RAP.

Proportioning by soil compaction methods is widely used in the UK and many countries in the world because it established the relationship between optimum moisture content and maximum dry density, satisfied the control compaction in the fact. The recent studies in developed countries in the world such as the US, France, Belgium, the Netherlands, Iran,... have mentioned using the proportioning by soil compaction methods to calculate and design mixture proportioning of RCC RAP in the construction of highway pavement such as foundation layer, sidewalks, car parking,...

On that basis, in the thesis, the proportioning by soil compaction methods is selected and used to calculate the design mixture proportioning of RCC RAP.

2.2. Research the mechanical and chemical properties of materials

2.2.1. Cement

Used 2 types of cement: But Son PC40, the Vissai PCB30, satisfied TCVN 2682:2009 and TCVN 6260:2009.

2.2.2. Aggregates

2.2.2.1. Coarse aggregate

Used coarses which had the size from 4,75–12,5 mm with Dmax = 12,5 mm, taken from Hoa Thach - Quoc Oai - Hanoi quarry. The mechanical properties were satisfied the current standards.

2.2.2.2. Fine aggregate

Used Lo river yellow sand with M_{dl} = 2,4. The mechanical properties were satisfied the current standards.

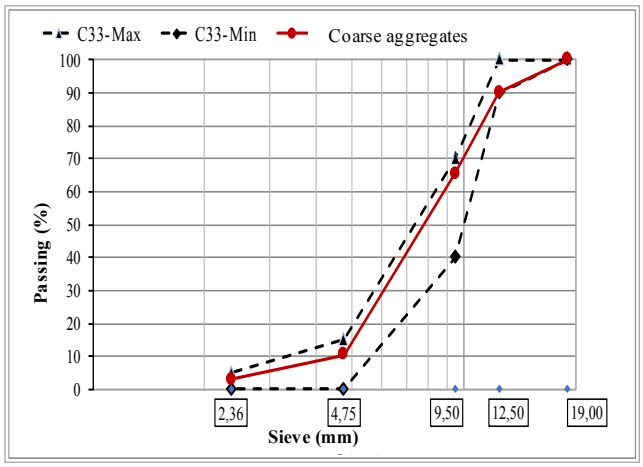


Figure 2-5. Gradation of coarse

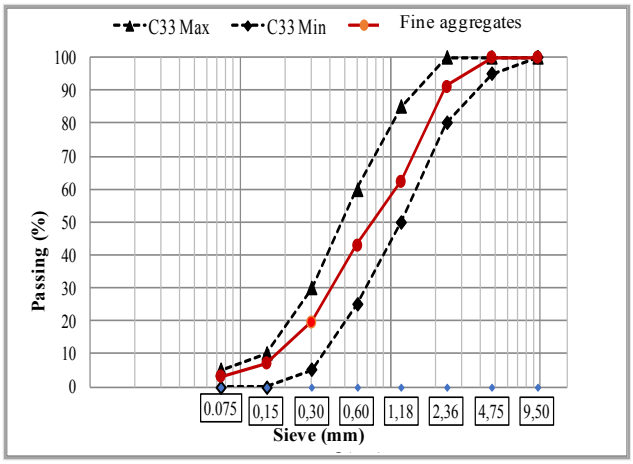


Figure 2-6. Gradation of fine aggregate

2.2.3. Reclaimed asphalt pavement

2.2.3.1. Source

Used 2 types of RAP collected from 2 different places.

- Type 1 (RAP1): collected from Tien Son Industrial Park - Bac Ninh.
- Type 2 (RAP2): collected on Phap Van - Cau Gie route.

2.2.3.2. The production process of reclaimed asphalt pavement in the laboratory

The reclaimed asphalt pavement was produced in the laboratory according to TCVN 11969:2018.

Figure 2-11. Coarse and fine aggregate after crushing and screening

2.2.3.3. Standards

The properties of RAP and RAP blends were according to the requirements of standards.

2.2.3.4. Research the mechanical and chemical properties of RAP

a. Gradation

The gradations of RAP1 and RAP2 were shown in figure 2-12 and figure 2-13.

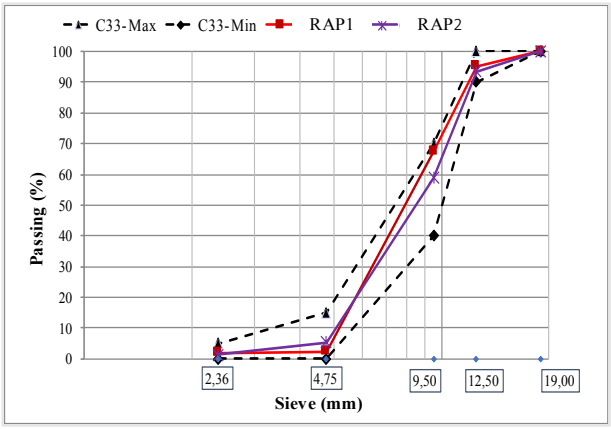


Figure 2-12. Gradation of coarse of RAP

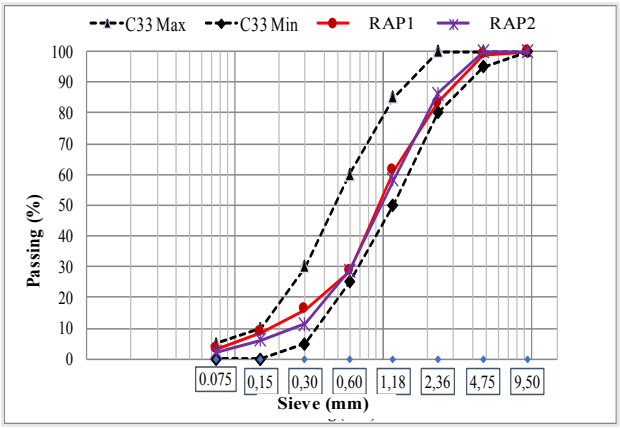


Figure 2-13. Gradation of fine aggregates of RAP

Base on the experiment results, the coarse of RAP1 and RAP2 also had D_{max} = 12,5 mm. The fine aggregates of RAP1 and RAP2 had M_{dl} = 3,0 and M_{dl} = 3,2. RAP1 and RAP2 both had the low percentage of fine aggregates below 0,075 mm (3,67% and 2,31%). This is a feature that should be noted when using RAP for RCC, it is necessary to add fine aggregates of less than 0,075 mm to ensure the required particle gradation of the aggregates mixtures.

b. The unit weight, density

The unit weight, density of RAP1 and RAP2 were showned in table 2-8.

Table 2-8. The unit weight, density of RAP1 and RAP2

No	Properties	Unit	C- RAP1	F-RAP1	C- RAP2	F-RAP2
1	Unit weight	g/cm^3	2,63	2,55	2,65	2,57
2	Density in dry condition	g/cm^3	2,56	2,51	2,57	2,53
3	Density in immersed condition	g/cm^3	2,59	2,52	2,60	2,52
4	Bulk density	g/cm^3	1,25	1,40	1,28	1,43

c. The bitumen extracted from RAP

The bitumen extracted from RAP was tested according to TCVN 8860, shown in figure 2-15

- The experiment results showed the bitumen extracted from RAP2 is higher than that of RAP1. So, with each other asphalt concrete, the bitumen extracted from RAP will be different.
- The experiment results showed: the bitumen extracted from coarse is lower than that of fine aggregates. Coarse of RAP1 and RAP2 had the bitumen extracted from RAP were 1,89% and 3,53%. The fine aggregates had the bitumen extracted from RAP were 3,53% and 5,76%

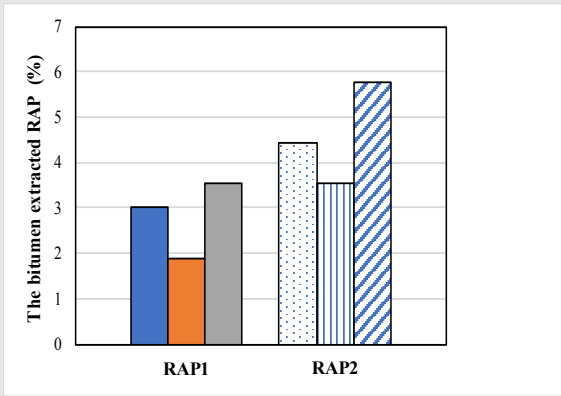


Figure 2-15. The bitumen extracted from RAP1 and RAP2

d. Absorption

The absorption of RAP was tested according to TCVN 7572-4-:2006 and TCVN 7572-5:2006. Figure 2-16, figure 2-17 showed the result of RAP1 and RAP2 before and after asphalt extraction.

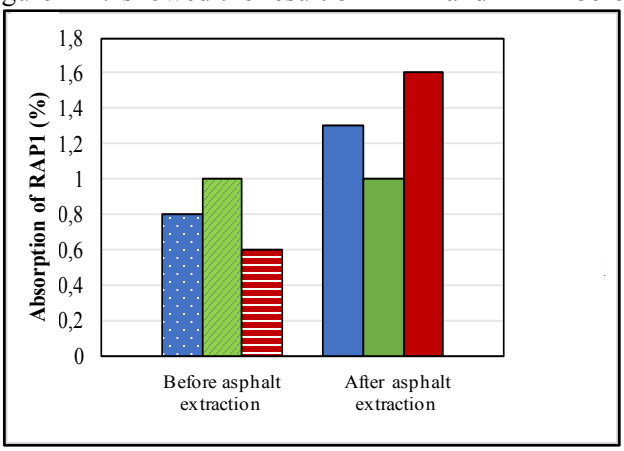


Figure 2-16. Absorption of RAP1 before and after asphalt extraction

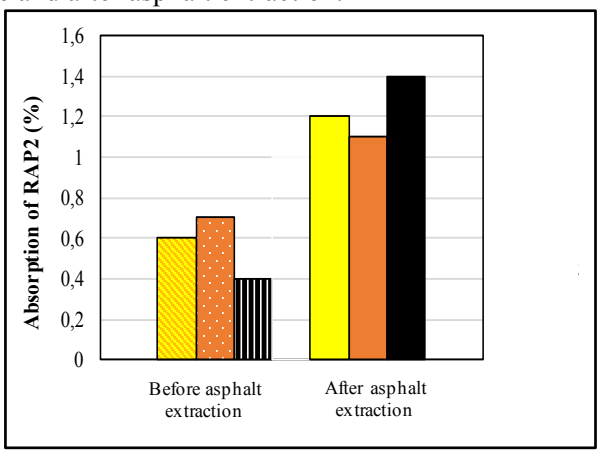


Figure 2-17. Absorption of RAP2 before and after asphalt extraction

The results showed that before asphalt extraction, the absorption of coarses was higher than that of fine aggregates. After asphalt extraction, the absorption of RAP was about 2-3 times that of before asphalt extraction because of the difference in the amount of bitumen between coarses and fine aggregates. And the absorption of coarses is greater than that of fine aggregates.

e. The content of dust, mud and clay of RAP

The content of dust, mud and clay were tested according to TCVN 7572-9:2006, showned in table 2-12.

Table 2-12. The content of dust, mud and clay of RAP

Aggregate	RAP1	RAP2
RAP (coarse and fine aggregate)	2,3	1,9
Coarse (> 4,75 mm)	1,8	1,1
Fine aggregate (< 4,75 mm)	3,2	2,5

2.2.4. Water

Water was clean water taken from Hanoi's factory water which according to TCVN 4506-2012.

2.2.5. Fly ash

Used fly ash of Cao Cuong Joint Stock Company, class F, the engineer properties were accorded to TCVN 8825:2011. Results of chemical composition and mechanical properties of fly ash used for roller compacted concrete were showned in table 2-14.

Table 2-14. Mechanical properties of fly ash

No	Mechanical properties	Uinit	Result	Require	Experimental standards
1	Unit weight	g/cm^3	2,1		ASTM C311-05
2	Amount retained when wet-sieved on 0,045	%	28,0	≤ 34	ASTM C430-05
3	Strength activity index 7 days	%	81,6	≥ 75	ASTM C311-05
	28 days		86,8	≥ 75	
4	Moisture content	%	0,52	≤ 3	

2.3. Calculate the model of mix design for RCC RAP

2.3.1. Combine dry coarse and fine aggregate in RCC RAP mixture

Used amounts of RAP at two levels: medium and high.

- 0% RAP (100% natural aggregates).
- 40% RAP (according to the total weight of aggregate mixture).
- 80% RAP (according to the total weight of aggregate mixture).

The combined aggregates was shown in Table 2-15.

Table 2-15. The combined aggregate (% of mass)

Combined aggregates	0% RAP	40%RAP	80%RAP
Coarses of RAP	0%	23%	44%
Fine aggregates of RAP	0%	17%	36%
Coarse of natural aggregates	50%	24%	0%
Fine aggregate of natural aggregates	50%	36%	20%
Total	**100%**	**100%**	**100%**

Figure 2-19 showned the curve of combined aggregate according to the table 2-15. Figure 2-20 shown the curve of combined aggregate after the addition of fly ash.

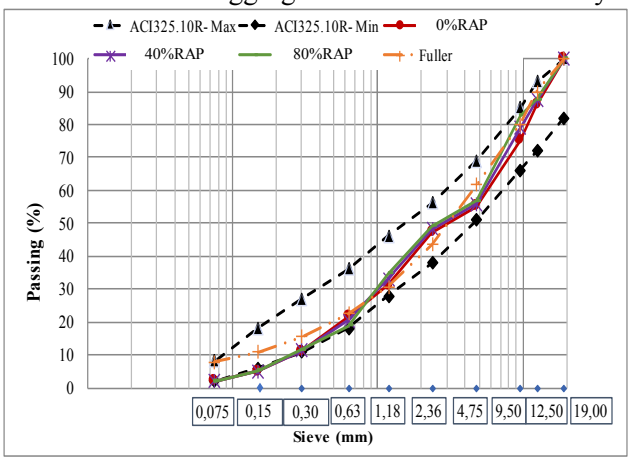


Figure 2-19. The curve of combined aggregate according to ACI 325.10R

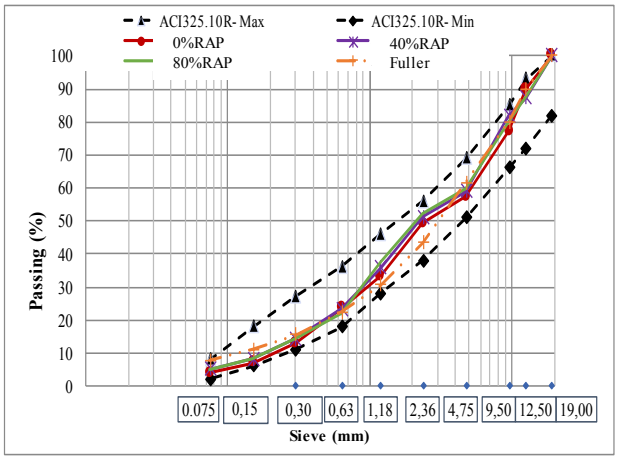


Fig 2-20. The curve of combined aggregate after the addition of fly ash

2.3.2. Select the amounts of cementitious materials

Used 3 amounts of cementitious materials (including cement and fly ash):

- 10% by mass of dry aggregates mixture.
- 13% by mass of dry aggregates mixture.
- 15% by mass of dry aggregates mixture.

The ACI 325.10R recommended fly ash contents generally range from 15% - 20% of the absolute volume of cementious materials. Calculate the fly ash content of 20% of the absolute volume of cementious materials according to the gradation of aggregate mixture in RCC RAP shown in Figure 2-10.

2.3.3. Determine the optimum moisture content

Determine the optimum moisture content according to ASTM D1557. For each combined of RCC RAP, 5 samples were moistened with 5 different water contents, defined the relationship between dry density and moisture content, so that finding the experimental regression function y(W).

$$y(W) = \gamma_d = aW^2 + bW + c \qquad (2.12)$$

From the equation, the optimum moisture content is determined corresponding to the maximum value of the function y(W).

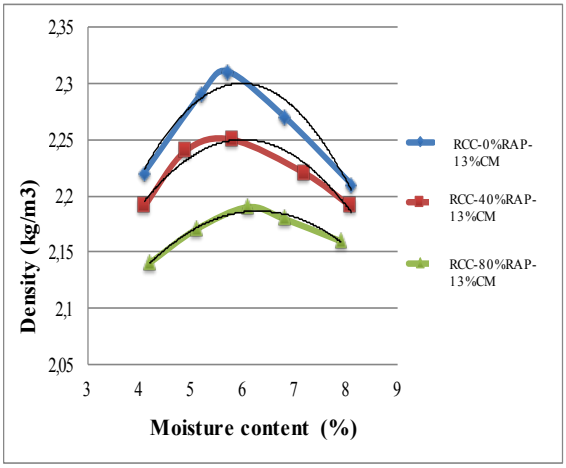


Figure 2-25. Relationship between dry density and moisture content of RCC RAP

The experimental results showned that the variation couvre of the optimum moisture content is between 5% and 6,5%, the water content was lower than that of normal cement concrete, allowing to no-slump concrete.

2.3.4. Calculate the absolute volumes and masses of the materials for the required unit volume of RCC RAP

From the combined aggregates, the amount of cementious materials, the optimum moisture content, the maximum dry density, calculate the absolute volumes and masses of the materials for the required unit volume of RCC RAP.

2.4. Conclusion of chapter 2

- The proportioning by soil compacted methods was selected to calculate the absolute volumes and masses of the materials for the required unit volume of RCC RAP.

- The mechanical and chemical properties of materials were evaluated by laboratory experimental study according to current standards. Then, by ACI 325.10R, ACI 211.3R, calculate the absolute volumes and masses of the materials for the required unit volume of RCC RAP which used 2 types of RAP1 and RAP2 from two different sources with two amounts of RAP (40% and 80%), using 2 types of cement (PC40 and PCB30) with 3 amounts of cementious materials (10%, 13% and 15%).

CHAPTER 3. LABORATORY EXPERIMENTAL STUDY TO EVALUATE THE ENGINEERING PROPERTIES OF RCC RAP

In this chapter, laboratory experimental study to evaluate the engineering properties of RCC RAP according to the current standards.

3.1. Experimental plan

General full factorial design was used by Minitab 20 at 95% confidence level, significance level = 5%. The number of sample group had 3 samples, the test results were evaluated according to the current standards.

3.2. Design of laboratory experimental

- The design of laboratory experimental was combined between theorerical and experimental methods.

Table 3-1. Summary table of the number of RCC RAP samples

Sample	Sample group	Type of RAP	The amount of CM	Type of C	The amount of RAP	Time
RCC	3	2	3	2	3	2
Total	3x2x3x2x3x2 = 216 samples					

- Evalute the engineering properties of RCC RAP such as compressive strength, splitting tensile strength, elastic modulus, complex modulus, water absorption and shrinkage.

3.3. Preparation of experimental samples

- In the conditions of laboratory at the UTT, the RCC RAP was mixed with a forced mixer.
- Cylindrical samples with diameter of 150 mm, height of 300 mm were manufactured according to 4452/QD-BGTVT. After 24 h of molding, the samples were unmolded and cured in water at room temperature until the age of the experiment.

Fig 3-1. RCC RAP is mixed with a forced mixer.

3.4. Laboratory experimental to evaluate the engineering properties of RCC RAP

3.4.1. Compressive strength of RCC RAP

The test evaluted the compressive strength of RCC RAP according to ASTM C39. Cylindrical sample 150 x 300 mm, carried out on 3 samples at 7 days and 28 days. Figure 3-4 and Figure 3-5 shown the results of compressive strength test of RCC RAP.

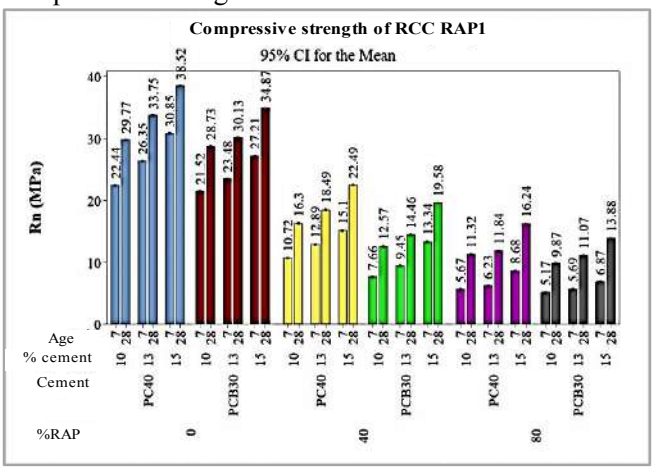


Figure 3-4. Diagram of compressive strength of RCC RAP1

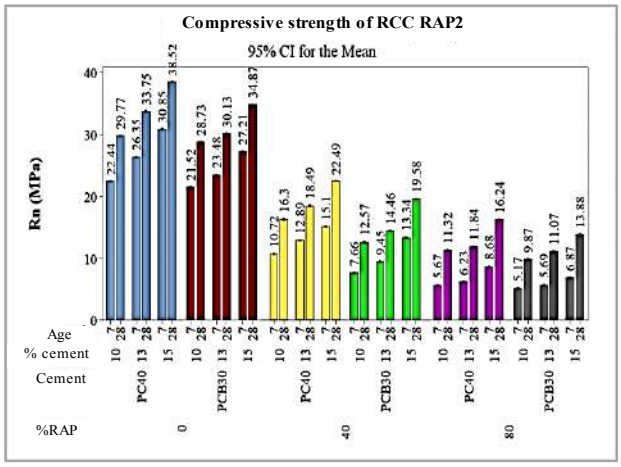


Figure 3-5. Diagram of compressive strength of RCC RAP2

- The experimental results showned that the main factors affecting the compressive strength of RCC RAP such as: type of RAP, the amount of RAP to replace natural aggregate, type of cement, the amount of cementious materials. In which, the most afected main factor of the compressive strength of RCC RAP was the amount of RAP.

- Compared with the control RCC, the compressive strength of the RCC RAP decreased when using 40% RAP and continued to decrease when increasing the amount of RAP from 40% to 80%. This is a point to keep in mind when using a high amount of RAP (over 50%) to replace natural aggregates in the RCC RAP.

- With the control RCC (100% natural aggregates), the effect of increasing the amount of cementious materials on compressive strength was more pronounced for RCC RAP, when using a higher the amount of

cementious materials of 10%, 13% and 15%, the compressive strength increases about 10% - 25% depending on the type of cement used.

- Experimental results also shown that the compressive strength of RCC RAP using PCB30 decreases about 15% - 20% than that of RCC RAP using PC40 which depending on the amount of RAP used.

3.4.2. Splitting tensile strength of RCC RAP

The test evaluted the splitting tensile strength of RCC RAP according to ASTM C496. Cylindrical sample 150 x 300 mm, carried out on 3 samples at 7 days and 28 days. Figure 3-13 and Figure 3-14 shown the results of splitting tensile strength test of RCC RAP.

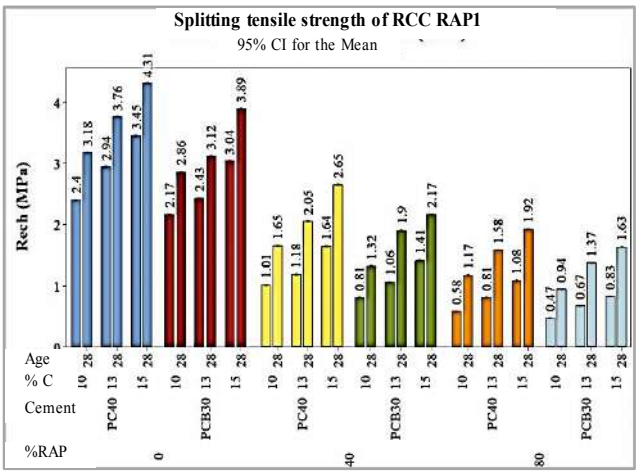


Figure 3-13. Diagram of splitting tensile strength of RCC RAP1

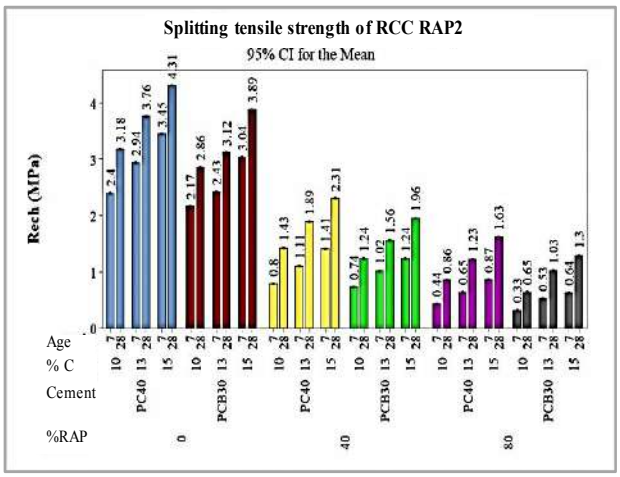


Figure 3-14. Diagram of splitting tensile strength of RCC RAP1

When testing for splitting tensile strength of RCC RAP, observing on the damaged surface of the control RCC and RCC RAP, the difference in the binding of natural aggregates with cement mortar and which of RAP with cement mortar. Figure 3-16a shown that the bond of natural aggregate with cement mortar is very good when the control RCC was damaged, the coarses also were broken. With the RCC RAP, because the outside of the RAP was covered the old asphalt layer, the bond between the cement mortar and the old asphalt layer was not uniform. When the sample was damaged, much of the RAP remained intact, not breaking apart like the natural aggregates showned in Figure 3-16b.

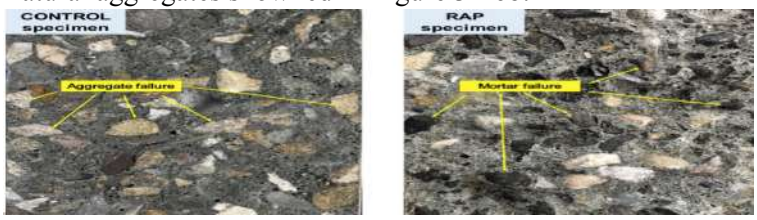


Figure 3-16. ITZ between RAP and NA with cement in RCC and RCC RAP

The experimental results shown the relationship equation of compressive strength and splitting tensile strength which was found. Figure 3-17 shown the relationship between splitting tensile strength and compressive strength of RCC RAP. The experimental regression of splitting tensile strength and compressive strength of RCC RAP was proposed:

$$Rn\ (MPa) = 2.248 + 8.559\ Rech\ (MPa) \quad (3.7)$$

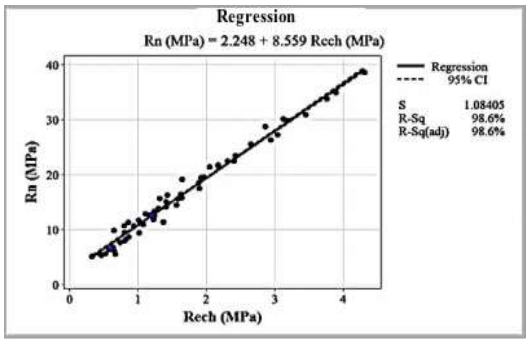


Figure 3-17. The relationship between splitting tensile strength and compressive strength of RCC RAP.

- The result of splitting tensile strength of RCC RAP was smaller than that of RCC control. Comparing to RCC, the splitting tensile strength of RCC-40%RAP had reduced in the range of 35% - 45%, that of RCC-80%RAP had reduced in the range of 50% - 60%. This is the basis for selecting the amount of RAP when calculate the absolute volumes and masses of the materials for the required unit volume of RCC RAP

3.4.3. Elastic modulus of RCC RAP

The test evaluted elastic modulus of RCC RAP according to ASTM C469. Cylindrical sample 150 x 300 mm, carried out on 3 samples at 7 and 28 days. Figure 3-19 and Figure 3-20 showned the results of elastic modulus test of RCC RAP.

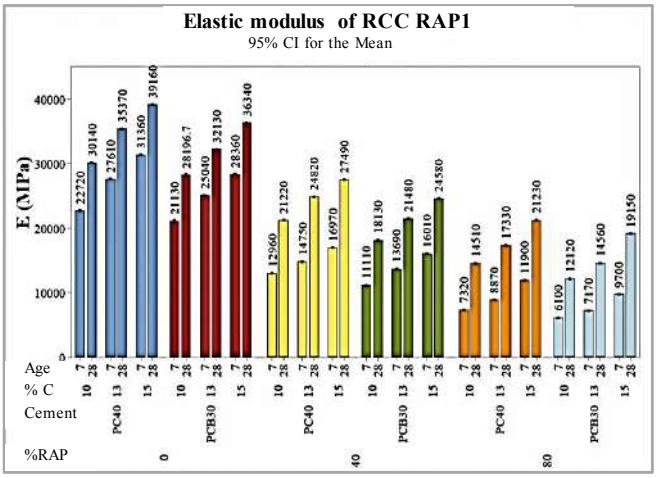


Figure 3-19. Diagram of elastic modulus of RCC RAP1

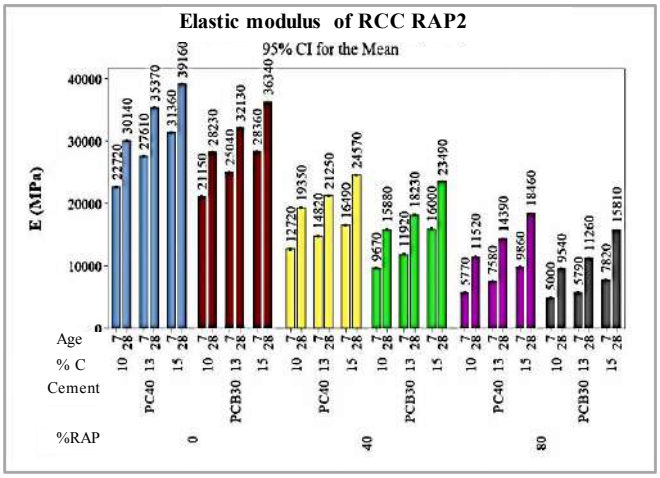


Figure 3-20. Diagram of elastic modulus of RCC RAP2

Base on the experimental results, found the relationship between the elastic modulus and the compressive strength of RCC RAP. When the value of compressive strength of RCC RAP was changed, the value of elastic modulus also was changed.

From figure 3-23, proposed experimental regression function of the elastic modulus and the compressive strength of RCC RAP:

$$E = 1{,}4387.(R_n)^{0{,}9127} \qquad (3.9)$$

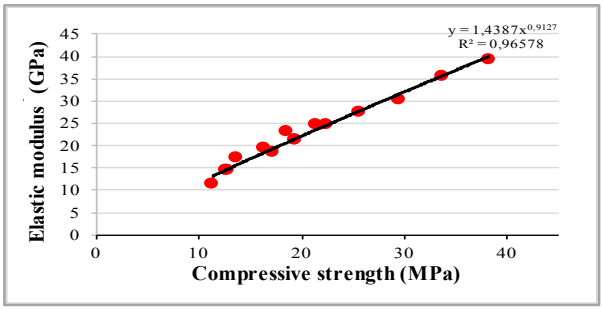


Figure 3-23. Relationship between the elastic modulus and the compressive strength of RCC RAP

The experimental results shown that the elastic modulus of RCC RAP had a smaller value than that of RCC control. Comparing to RCC, RCC-40%RAP had the value of elastic modulus at 28 days reduced by about 30%, RCC 80% RAP had the elastic modulus value at 28 days old reduced by about 45% - 55%.

The plasticity of RCC RAP was increased due to the appearance of an old asphalt layer. Due to the visco-elastic asphalt layer engulfing the RAP, the crack propagates around the ITZ of the RAP and the mortar rather than the propagation of the cracks through the aggregates was seen in the case of RCC containing natural aggregates. The elastic modulus will effectively control the crack width, so the RCC RAP could bring sustainable efficiency in the construction of highway pavement.

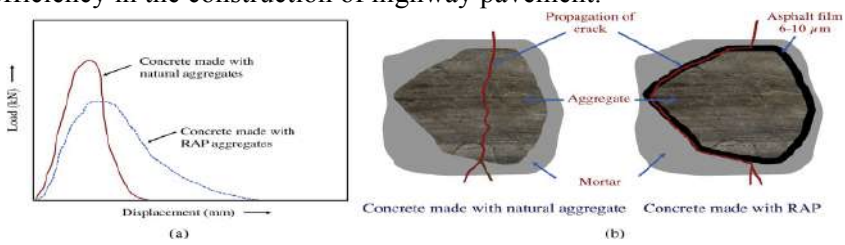


Figure 3-24. The propagation of crack in RCC and RCC RAP

3.4.4. Dry shrinkage

RCC RAP were fabricated with dimensions of 100x100x400 mm. The change in length of the samples at the end of 1, 7, 14, 28, 56 days was tested according to TCVN 3117: 1993, showned in Figure 3-26.

Base on the experimental results, at the standard temperature of 25 ± 2°C, the shrinkage of RCC RAP was larger than that of RCC. This could be explained by the visco-elastic asphalt layer of RAP particles when contacted with the cement mortar, there would be voids in RCC RAP, so the shrinkage of RCC RAP would be reduced. So the value of RCC RAP was heigher than that of RCC.

When the amount of RAP changed, the shrinkage also changed, specifically, RCC-80%RAP had a larger shrinkage than that of RCC-40%RAP. At the same time, it was observed that the general trend of shrinkage was strong in the first 28 days and then the growth trend was gradually decreasing over time.

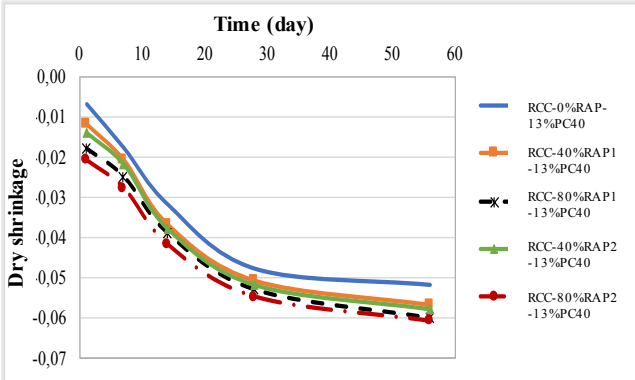


Figure 3-26. Diagram of dry shrinkage of RCC RAP

3.4.5. Density of RCC RAP

- The results of the experiment to determine the density of RCC RAP were showned in Figure 3-27.

The density of RCC RAP depended on the density of the fabrication materials. When using RAP to partially replace natural aggregate of RCC, the density of RCC RAP was lower than that of control RCC (0% RAP) because of the old asphalt layer wrapped around RAP. So, the replacement of natural aggregate with RAP had reduced the density of RCC RAP compared with the density of RCC control.

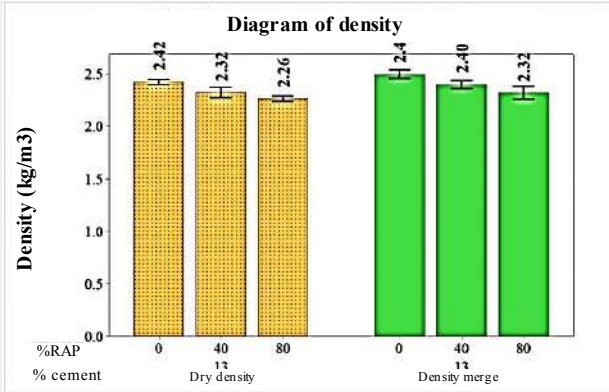


Figure 3-27. Diagram of density of RCC RAP

3.4.6. Absorption of RCC RAP

- The results of the absorption test were showned in Figure 3-28.
- The experimental results shown that the absorption of RCC RAP decreased as the amount of RAP increases. This could be explained by the old asphalt layer wrapped around RAP which preventing water penetration into the pores of the aggregates.

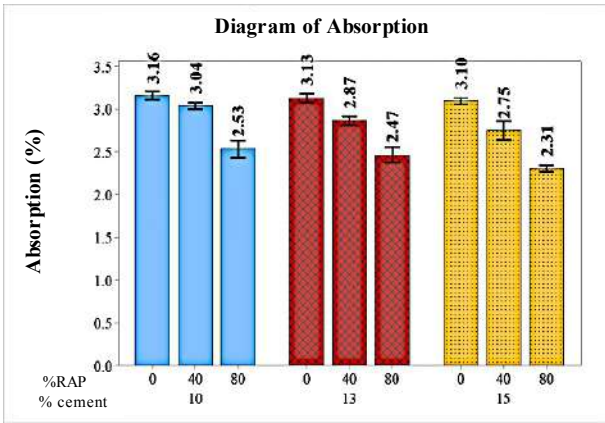


Figure 3-28. Absorption of RCC RAP

3.4.7. Complex modulus of RCC RAP

- Used Cooper of University of Transport, according to AASHTO TP-62.
- Experimental plan included:

+ Type of cement: PCB30; PC40
+ Amount of RAP: 40%; 80%
+ Temperature: 30; 40; 50°C
+ Frequency: 0,1; 0,5; 1,0; 5,0; 10,0; 25,0 Hz

The total number of experimental samples is 2x2x3x6x4 = 288 samples.

Figure 3-32 shown the curves of complex modulus of RCC RAP, basically they were the same curves, but the position of the curves depended on the type of cement and the amount of RAP.

- With the highest curve, the maximum value of |E*| was the curve of RCC-40%RAP-PC40. The lowest curve which had the minimum value of |E*| was the value of RCC-80%RAP-PCB30. The curves also shown that when the frequency increased (the shorter the duration of the load), the value of |E*| of RCC RAP increased.
- Type of cement: RCC RAP - PC40 had the value of |E*| higher than that of RCC RAP - PCB30, this effect was shown by the slope of the straight line;
- Temperature: greatly affect |E*|, when the temperature was increased, the value of |E*| was decreased quickly.
- The higher the frequency the smaller the effect time, leading to the value of |E*| greater.

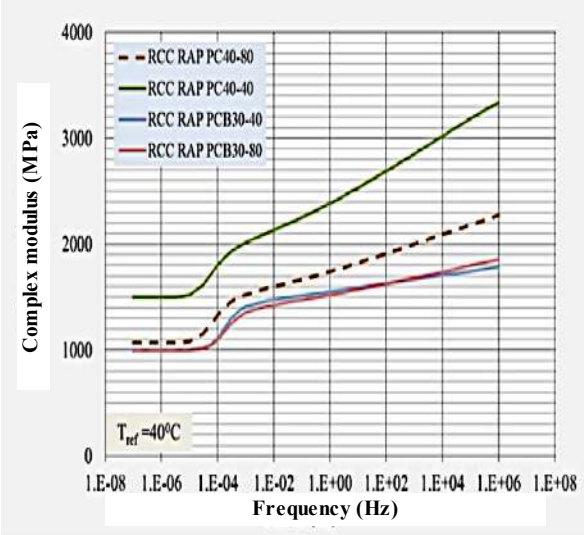


Figure 3-32. The curves of complex modulus of RCC RAP

- Amount of RAP: Effect of the amount of RAP on the value of |E*| was very large, when increasing the amount of RAP from 40% to 80%, then the value of |E*| decreased, as shown by the downward slope of the histogram;

Although the complex modulus was not used in the calculation of the rigid pavement structure because of hadn't specified standard, the test of the complex modulus shown that the visco-elastic asphalt layer around the RAP affected the mechanical properties of RCC RAP. This is the basic premise for the future research which is to clarify the influence of the amount of RAP, of the old asphalt layer wrapping RAP and the degree of aging of the old asphalt layer on the mechanical properties of RCC RAP.

3.5. Conclusion of chapter 3

- The replacement of natural aggregate with a part of RAP affected the mechanical properties of RCC RAP. The changement of mechanical properties of RCC RAP depended on the amount of RAP. Experimental results shown that when using 40% RAP, the mechanical properties of RCC were affected, but when using high amount of RAP (80%) the mechanical properties of RCC were greatly reduced. The higher the amount of RAP, the lower the strength of RCC. Therefore, the use of high amount of RAP (>50%) in RCC RAP should be carefully considered to be suitable for use in construction of highway pavement.
- The amounts of cementious materials which varying from 10%, 13% and 15% significantly affected the mechanical properties of RCC RAP. PC40 can be used instead of PCB30 to improve the mechanical properties of RCC using high amount of RAP.
- Base on the experimental result of the complex modulus, the cuvre of |E*| was found similar to that of asphalt concrete. Therefore, part of the visco-elastic asphalt layer of RAP participates in the material

behavior under the effect of load and temperature. This was the effect of old the visco-elastic asphalt layer of RAP on the mechanical properties of RCC RAP.

- Select one of RCC RAP as the basis for the construction of highway pavement. It is RCC – 40% RAP – 13% PC40. At the age of 28 days, it has R_n = 18.49 MPa; R_{ec} = 1.89 MPa; E = 23250 MPa.
- With the laboratory experimental results, the RCC RAP had a certain efficiency. Therefore, the application of cold recycling asphalt pavement in mixing plants in the construction of highway pavement is necessary, has practical scientific significance, and brings technical efficiency and effectiveness economically, makes full use of waste materials, reduce environmental pollution, save on exhausted natural materials.

CHAPTER 4. CONSTRUCTION OF THE EXPERIMENTAL RCC RAP PAVEMENT AND RESEARCH PROPOSED FOR PAVEMENT STRUCTURES USING ROLLER COMPACTED CONCRETE CONTAINING RECLAIMED ASPHALT PAVEMENT

In this chapter, constructed a experimental RCC RAP pavement. Then, studied field tests to evaluate the mecanical properties of this road. Finally, proposed some pavement structures using RCC RAP in construction of highway pavement in Vietnam.

4.1. Construction of the experimental RCC RAP pavement

4.1.1. Summary of construction plan

The construction plan wss carried out in the following order:

- Proposed the experimental RCC RAP pavement with low traffic volume, light load.
- Calculation of design of the experimental RCC RAP pavement.
- Tested technical properties of the RCC RAP pavement.
- Analysis and evaluation of the technical properties of the RCC RAP pavement.

4.1.2. Propose pavement structure of RCC RAP

1. Specifications

- Grade IV with light traffic, V = 50km/h, allowing natural cracking due to shrinkage. Design life: 10 years, P_s = 100 kN, P_{max} = 120 kN.

2. Estimated pavement structure

- The surface layer of RCC RAP had the thickness of 20cm, f_r = 3,02 MPa; E = 23250 MPa; R_n = 18,49 MPa; RCC RAP plate had dimensions of 4,0m x 5,0m, the horizontal joint had not a force rod.
- The foundation layer was made of crushed stone grade I with E = 300 MPa, the thickness of 20cm, placed directly on the ground, no need to design the lower foundation layer because of the light load.
- The ground had E = 40 MPa.

3. Estimated structure audit: Calculation of RCC RAP pavement according to 4451/QD-BGTVT.

4. Comment: The RCC RAP pavement achieved the allowable limit conditions. Thus, the RCC RAP layer could be used as a pavement structure with medium-sized traffic or less. To ensure smoothness and avoid water seeping through the plate, 1-3 layers of bitumen or emulsion could be applied on the surface layer.

4.1.3. Construction of the experimental RCC RAP pavement

- Determined the location, plan and geometrical parameters of the experimental RCC RAP pavement.
- Preparation of RAP.
- Construction of the foundation layer.
- Construction of crushed stone grade I.
- Construction of the experimental RCC RAP pavement.

Figure 4-3. Location of construction

Figure 4-20. The experimental RCC RAP pavement.

4.1.4. Evalution of the mechanical properties

4.1.3.1. Measure and monitor the the progress of cracks after construction

a. For 24 hours

- The cracks in the surface occured within 24 hours after construction. Cracks were very diverse including: longitudinal, transverse and oblique. Length and depth of cracks at places where aggregates were unevenly distributed and uneven rolling were not large but zigzag, width of cracking was less than 1mm. At places where the aggregate were evenlt distributed on the surface, without stratification, it had few cracks, the surface was smooth and flat.

b. For 24-72 hours

- The cracks in the surface of the RCC RAP pavement still tended to increase but it was not obvious. Particularly, the crack width had not increased after 24 hours. Observing with the naked eye, the crack on the surface had different density and width of cracks were also different.

a. For 24 hours

b. For 24-72 hours

Figure 4-21. The surface of the RCC RAP pavement

c. Evalution

- The cracks in the surface layer of the experimental RCC RAP pavement developed over time in density, length and width of cracks. However, after curing, the method of spraying water to wet the surface layer to cure it, especially in hot weather, cut the joints according to standards, the cracks in the surface of the RCC RAP pavement developed slowly, the crack width did not increase.

4.1.3.2. Evalution of the the experimental road using RCC RAP

The flatness of the RCC RAP pavement in the longitudinal direction decreased over time but still was satified the requirements according to TCVN 8864:2011.

Bảng 4-8. The flatness of the RCC RAP pavement

Crack	<3mm	3 - 5mm	5 -7mm	7 - 10mm	10 - 15mm	15 - 20mm	>20mm	Lý trình
After 1 month								
Percentage (%)	82,4	10,5	0	0	0	0	0	Km0+5
	78,6	8,2	0	0	0	0	0	Km0+15
After 12 months								
Percentage (%)	74,3	11,2	0	0	0	0	0	Km0+5
	67,7	9,5	0	0	0	0	0	Km0+15

4.1.3.3. Laboratory experimental study to evaluate the mechanical properties of the RCC RAP pavement

a. Compressive strength of RCC RAP pavement

- The compressive strength were tested on 9 samples at 7, 14 and 28 days.
- Results of compressive strength of the RCC RAP pavement developed over time which reflected the same results in the laboratory.
- The compressive strength developed rapidly in the 7 days. The value of compressive strength of drilled samples at 28 days = 17,77 MPa < 18,48 MPa but still met the technical requirements.

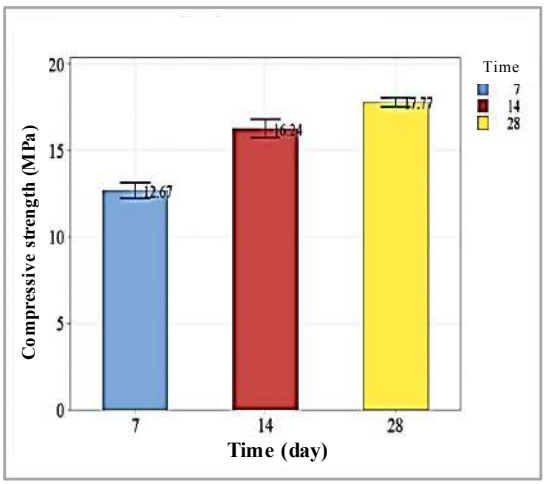


Figure 4-24. Diagram of compressive strength of RCC RAP pavement

b. Splitting tensile strength of RCC RAP pavement

- The split compressive strength were tested on 9 samples at 7, 14, 28 days.
- Results of split compressive strength of the RCC RAP pavement developed over time which reflected the same result in the laboratory.
- The split compressive strength developed rapidly in 7 days. The value of split compressive strength of drilled samples at 28 days = 1,70 MPa < 1,78 MPa but still met the technical requirements.

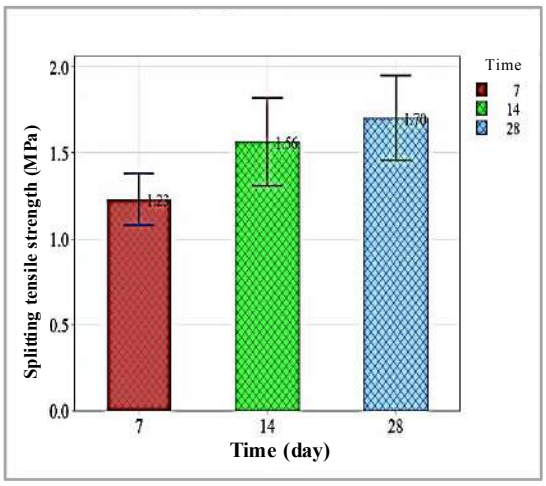


Figure 4-26. Diagram of splitting tensile strength of RCC RAP pavement

c. Elastic modulus of RCC RAP pavement

- The elastic modulus were tested on 9 samples at 7, 14, 28 days.
- Results of the elastic modulus of the RCC RAP pavement developed over time which reflected the same result in the laboratory.
- The elastic modulus developed rapidly in 7 days. The value of elastic modulus of drilled samples at 28 days = 23150 MPa < 23250 MPa but still met the technical requirements.

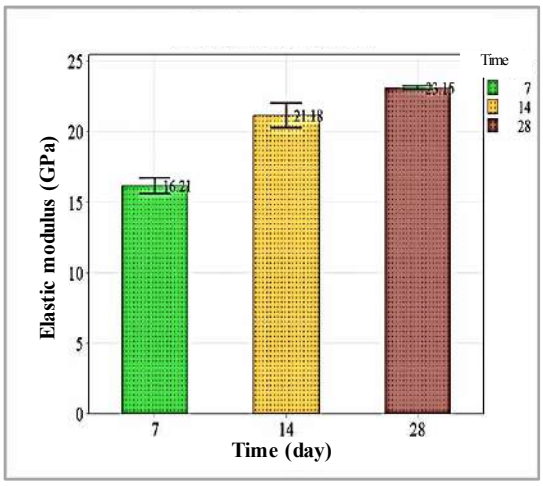


Figure 4-28. Diagram of elastic modulus of RCC RAP pavement

4.1.4. Evalution

- The RCC RAP pavement was construited on 20th February 2019 and was completed on 27th February 2019.
- The mechanical properties of The RCC RAP pavement were met the requirements of the Vietnamese construction standards. After more than 3 years of construction, the RCC RAP pavement has been still intact with no signs of damage. Base on the experimental results of the drill samples and comparing with the technical requirements, the RCC RAP pavement could be used as a pavement structure in construction of highway pavement in Viet Nam.
- For segment with pseudo-slit cutting: After cutting of joints, no more cracks appeared and pre-existing cracks did not expand further. With the sections without pseudo-slit cutting, the crack width on the surface of the RCC RAP pavement tended to grow, but the crack width wss not more than 2,0 mm, the density of crack did not increase.

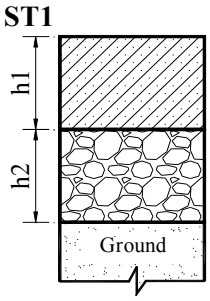
Figure 4-29. The RCC RAP pavement from construction to 3 years later

4.2. Propose pavement structures using roller compacted concrete containing reclaimed asphalt pavement

With the results of laboratory research and experimental RCC RAP pavement, continued to study the scientific and practical basis to propose some pavement structures using RCC RAP which were met the technical requirements, minimized environmental impacts, reused of waste materials and saved natural resources of materials.

*** Calculating of the proposed pavement structures using roller compacted concrete containing reclaimed asphalt pavement was shown in table 4-16**

Table 4-16. Calculating of the proposed pavement structure using RCC RAP

Structure	Parameter		Application
	Layer	Thickness, cm	
ST1 	RCC- 40% RAP1-13%PC40: R_n = 21,39 MPa; E =24,82 GPa; R_{ku}= 3,28 MPa	20	- Grade IV P_s = 100 kN; P_m = 240 kN; N_e = 1.10^6 times/lane. t = 10 years - bxl = 4x5m
	Reinforced coarses by cement: E=450 MPa; K_2=320 MN/m^3	12	
	Ground, K_3=40 MN/m^3		

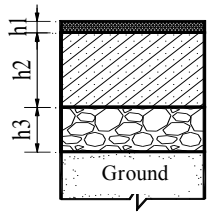
Result: σ_{pmax} = 2,75 MPa → $\gamma_r.\sigma_{pmax}$ =1,07*2,75 = 2,94 ≤ f_r =3,28 : satisfied

σ_{pr} = 1,46 MPa → $\gamma_r.\sigma_{pr}$ = 1,07*1,46 =1,56 ≤ f_r =3,28 : satisfied

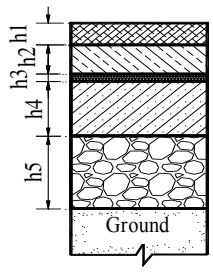
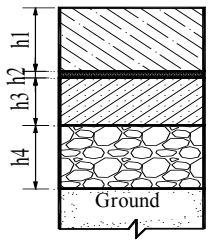
The stress of RCC RAP pavement was still lower than the allowable limit, however, because the structural conditions were not satisfied, so the pavement structure of RCC RAP was not used as the structure pavement according to Decision 3230/QD-BGTVT.

Therefore, the proposed pavement structures were as follows:

Figure 4-17. The proposed pavement structures using RCC RAP

Structure	Parameter		Application
	Layer	Thickness, cm	
ST2 	- 3 asphalt layers according to TCVN 8863:2011	3,0 - 3,5	- According to 4451/QĐ-BGTVT - Traffic volume 100 - 200 vehiles /day - Light > 6000 Kg
	- RCC 40% RAP	20 - 25	
	- Crushed stone layer	15 - 20	
	- Ground		

Figurre 4-18. The proposed pavement structures using RCC RAP

Structure	Parameter		Application
	Layer	Thickness, cm	
ST3 	- BTA 12,5	5 - 6	- Grade A1 - According to 22TCN 211-06 or 22TCN 274-01 - E_{yc} = 140-160 MPa
	- BTA 19	7 - 8	
	- 1-2 asphalt layers according to TCVN 8863:2011	1,5 - 2,5	
	- RCC 40% RAP	16 - 20	
	- Crushed stone grade II	15 - 30	
	- Ground		
ST4 	- Cement concrete f_r=4,5÷5,0 MPa	20 - 25	- According to 3230/QĐ-GTVT - Heavy traffic volume
	- Separation layer	1 - 3	
	- RCC 40-80% RAP	16 - 20	
	- Crushed stone	15 - 30	
	- Ground		

4.2.6. Comparing and evalution of the construction cost of RCC RAP pavement and the concrete normal pavement

Construction of car parking with a length of 50m and a width of 20m using 03 types of pavement structures such as RCC RAP, BTXM M20, BTXM M25 which using PC40, sand and stone taken from the same mine, same water source, same type of mixing plants, had the same transport distance and used SP500 spreader. Specifications: P_s = 100 KN, P_{max} = 120 KN, met the requirements of the current standards.

Summary of construction costs of the pavements

No	Pavement structure	Cost content (VND)
1	RCC RAP	295.118.123
2	Cement concrete M20	357.943.521
3	Cement concrete M25	339.208.282

The construction costs of the pavement structure using RCC RAP, cement concrete M20 and cement concrete M25 shown that the construction cost of the RCC RAP pavement was 13,0% of the construction cost of the cement concrete M20 pavement so it was cheaper than that; was 17,6% of the construction cost of the cement concrete M25 pavement so it was cheaper than that. Thus, the use of RAP to partially replace natural aggregates to make RCC RAP pavement made economic sense, lowerd the construction costs, and saved natural materials.

4.3. Conclution of chapter 4

- Evaluating the experimental RCC RAP pavement after 3 years of construction, it has been still intact, there is no signs of damage, no cracks or local vandalism are detected.

- The results of experimental study of the RCC RAP pavement were also satisfied the technical requirements, so RCC RAP pavement could be used as the foundation layer of high-grade roads, making the surface layer of low-grade roads, car parking lots,...

- Proposing pavement structures using RCC RAP. Modeling and calculation of the pavement structure of RCC RAP.

- Base on the experimental results and the calculation of pavement structure, it can be concluded that the application of cold recycling asphalt technology such as RCC RAP is completely reasonable, has scientific and practical contribution, saving construction costs and natural materials, reducing the cost of transporting new aggregates from other places, reusing of waste materials, and protecting the environment.

CONCLUSION AND RECOMMENDATION

I. Conclusion

1. Proposed mixture proportioning using ACI 325.10R, ACI 211.3R specification based on soil compaction methods to calculate and design the composition of the RCC RAP in the construction of highway pavement in Vietnam.
2. Carried out laboratory experimental study to evaluate the mechanical properties of roller compacted concrete using two types of RAP collected from two different sources with different RAP contents (0%, 40% and 80%) and different contents (10%, 13% and 15%) of cementitious material using PCB30 or PC40 cements. From there, applied the cold recycling technology at mixing plants to produce RCC RAP for application in construction of highway pavements with suitable conditions for Vietnam.
3. Initially analyzed the influence of old asphalt binder in RAP on the mechanical properties of RCC RAP. Base on the experimental results, the experimental regression functions were found as follows:

   - Between compressive strength and split compressive strength:

   $$R_{ec} = 0,3224 + 0,08318.R_n \text{ (MPa)}$$

   - Between compressive strength and elastic modulus:

   $$E_{bt} = 1,4387.(R_n)^{0,9127} \quad \text{with } R^2 = 0,9127$$

4. Design and construction of an experimental RCC RAP pavement at Vinh Yen campus of University of Technology and Transport. The RCC RAP pavement had a width of 3.5 m and a length of 20 m. After that, conducting field tests to evaluate the basic mechanical properties (compressive strength,

splitting strength, elastic modulus) according to current Vietnamese standards, and at the same time, monitoring the behavior of the RCC RAP pavement. After more than 3 years, the experimental RCC RAP pavement has been still intact. There are no signs of damage, the crack density does not increase and there is no local failure.

5. Proposed and recommended 5 pavement structures using RCC RAP in the construction of highway pavement. It was concluded that RCC RAP can be used as a foundation layer in high-grade roads, or a surface layer for low-grade roads, car parking, sidewalks,..., suitable for various conditions in Vietnam. Adding the cold recycling asphalt pavement technology in mixing plants to take advantage of available waste materials, to reduce construction costs and to reduce environmental pollution. This research has scientific and practical contributions, and is a reference or future research studies.

II. Research orientation

1. Continue to experimental study to evaluate the influence of the old asphalt layer in RAP on the mechanical properties of RCC RAP, laboratory experimental study on abrasion, cracking, coefficient of thermal expansion,... of RCC RAP.
2. It is necessary to continue to research the application of RCC RAP with the different amount of RAP and the different amount of cementiuos materials for application in the construction of highway pavement, saving natural materials, making use of waste materials, and limiting environmental pollution.

AUTHOR'S PUBLICATION LIST

1. Nguyen Thi Huong Giang, Bui Xuan Cay, Nguyen Mai Lan, Tran Trung Hieu, Nguyen Tien Dung (2018), "Evalute the mecanical properties of reclaimed asphalt pavement applying roller compacted concrete as the pavement structure in Viet Nam*, Transport Journal No 12/2018.*
2. Nguyen Thi Huong Giang, Bui Xuan Cay, Đao Van Đong, Nguyen Mai Lan, Tran Trung Hieu, Nguyen Tien Dung (2019), "Investigation of the use of reclaimed asphalt pavement as aggregates in roller compacted concrete for road base pavement in Viet Nam", *CIGOS 2019.*
3. Nguyen Thi Huong Giang, Bui Xuan Cay, Le Quang Huy (2021), "Research the applicability of roller compacted concrete contain reclaimed asphalt pavement in construction of highway pavement in Vietnam", *Viet Nam Bridge and Road Magazine No 4-2021.*
4. Nguyen Thi Huong Giang, Đao Phuc Lam, Nguyen Tien Dung, Le Quang Huy (2021), "Calculate the model of mix design for roller compacted concrete containing reclaimed asphalt pavement", *The builder No 3-4-2021.*