International Journal of GEOMATE, Dec., 2019 Vol.17, Issue 64, pp. 77 - 84
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2019.64.08722
Geotechnique, Construction Materials and Environment

INFLUENCE OF CEMENT AND ASPHALT EMULSION RATIOS ON CEMENT-ASPHALT EMULSION MORTAR

Patcharapan Nanthavisit[1], Peerapong Jitsangiam[2] and *Preda Pichayapan[2]

[1] Graduate School and Department of Civil Engineering, Faculty of Engineering, Chiang Mai University, Thailand; [2] Excellence Center in Infrastructure Technology and Transportation Engineering (ExCITE) and Department of Civil Engineering, Faculty of Engineering Chiang Mai University, Thailand

*Corresponding Author, Received: 04 July 2019, Revised: 07 Aug. 2019, Accepted: 27 Aug. 2019

ABSTRACT: It is known that cement has been used as a stabilizing agent for the road pavement stabilization**.** However, it could cause an adverse effect of premature cracking on the road**.** Moreover, asphalt emulsion has been a famous agent for pavement stabilizing as well, even though it has revealed low deformation resistance**.** Therefore, this research aims to investigate resulting from the mixture of cement and asphalt emulsion, which is called cement-asphalt emulsion as a new stabilizing agent**.** This mixture provides more flexibility and waterproofing by using asphalt emulsion features, and high strength from cement**.** Cement**-**asphalt emulsion mortar; the mixture of Portland cement type I, cationic asphalt emulsion **(**CSS-1**)**, and standard sand, were used as the study material**.** Cement**-**asphalt emulsion mortar was a various type of cement and asphalt emulsion ratios for the compressive strength test and flexural strength test**.** The test results presented that the compressive strength and the flexural strength decrease with an increase of asphalt emulsion**.** Ratio 4**:**1 **(**cement**:** asphalt emulsion**)** exhibited the highest compressive strength and the flexural strength at 7 days and 28 days testing with controlled relative humidity curing**.** This ratio then should be recommended to apply in pavement stabilization**.**

Keywords: Cement-Asphalt emulsion ratio, Cement-asphalt emulsion mortar, Compressive strength, Flexural strength

1. INTRODUCTION

Pavement stabilization is a process to improve bearing capabilities and performance of the pavement. The mechanisms of pavement stabilization can be divided into two broad areas, mechanical stabilization, and chemical stabilization. Mechanical stabilization includes compaction, the blending of aggregates to improving gradation, and the addition of asphalt. Chemical stabilization includes the addition of materials such as lime, cement, and fly-ash in combination or alone. These materials either react chemically with the material being stabilized or react on their own to form cementing compound [1**]**.

Asphalt emulsion is a famous agent for pavement stabilization**.** It is one of the technologies that allow asphalt to be mixed at lower temperatures**.** It does not react chemically with the materials while being stabilized but it coats the particles, increases adhesion and waterproof**.** Asphalt emulsion contained 70**%** asphalt, water around 30**%**, and typically less than 1**.**5**%** of chemical additives**.** There are two main types of asphalt emulsion; cationic asphalt emulsion and anionic asphalt emulsion**.** The asphalt emulsions are used in a wide variety of applications such as the chip seal, the slurry seal, the cold-mixed asphalt, and the cold-in-place recycling**.**

Moreover, the cement stabilization is also a popular technique to stabilize poorer aggregates and existing roadway, especially improving bearing capacity. However, the cementitious materials usually occur the shrinkage behavior because of the development of moisture suction forces when the cement dries. In other words, the shrinkage mainly depends on the moisture loss in fine pores, or during the hydration process of cement.

Cement is commonly used as a stabilizing agent for road construction in Thailand, especially to improve the properties of substandard road construction materials. Many stabilization projects used cement for stabilization. Those projects have to face premature damages caused by shrinkage cracking in the cement-stabilized base layer **[**2**]**.

The combination of asphalt emulsion and cement has improved various efficiency of pavement, such as initial strength, dry tensile strength, rutting resistance, moisture susceptibility, resilient modulus, and CBR value. This new concept of cement-asphalt emulsion mixture could be a good alternative to improve a sustainable performance of base course and pavement stabilization. Based on the concept that cement content controls the elastic modulus, while asphalt emulsion content gives the strain capacity of cement-asphalt emulsion mixture, a combination of optimum cement and optimum asphalt emulsion content would result in better mixtures performance. This combination could also reduce cement's absorption ability, and increase the resistance of hydrating ions of the emulsions. Additionally, it can improve mixing stability, workability, and mechanical properties when adding cement into asphalt emulsion [3]. The cement-asphalt emulsion possesses most of the characteristics of both cement and asphalt, which are longer fatigue life and lower temperature susceptibility of cement concrete, and higher toughness and flexibility of asphalt concrete [4-6].

Many studies have reported that the cold mix and the cold recycling with asphalt emulsion and cement as a filler can improve moisture damage resistance and early stiffening, and accelerate the breaking time of asphalt emulsion. In the case of cement-asphalt emulsion paste and cement-asphalt emulsion mortar, many researchers studied about mechanical properties and rheological properties of those cement-asphalt emulsion composite. The results of cement-asphalt emulsion paste and cement-asphalt emulsion mortar is found to be quite similar to cold mix and cold recycling with asphalt emulsion and cement as a filler, especially when mixtures present a high strength and better moisture resistance.

Types of asphalt emulsion, types of cement, relative humidity, and curing period affect mechanical properties and rheological properties of the cement-asphalt emulsion composite. The different types of asphalt emulsion yields in the different rheological properties of cement-asphalt emulsion paste and mortar. The cationic emulsion provided a higher compressive strength than anionic asphalt emulsion [7].

Adding different types of cement powder into cationic and anionic asphalt emulsion illustrates the difference results; for example, the anionic asphalt emulsion with Portland cement is more effective than the cationic type because of the favorable adsorption onto the surface of cement grains [8]. The mixing stability of cationic emulsions with limestone powder is better than the anionic emulsions. Besides, adding cement changes the pH value of cationic emulsion but has no effect on anionic emulsion [3]. The powerful retardation effect of anionic asphalt emulsion causes good flowability of cement-asphalt emulsion paste. While the cationic asphalt emulsion has stronger temperature dependence than the cement-asphalt emulsion with an anionic asphalt emulsion.

Increasing temperature decreases the viscosities of both anionic and cationic asphalt emulsions. For the anionic asphalt emulsion, the high asphalt content in cement-asphalt emulsion pastes causes a low effect of temperature change on the growth of yield stress. However, for the cationic asphalt emulsion, an increase in asphalt content in cement-asphalt emulsion pastes leads to the strong temperature dependence of yield stress growth because of the inconsistency of the cationic asphalt emulsion at high temperature and weak retardation effect on cement hydration [8].

The increase in asphalt emulsion to cement ratio resulted in decreasing workability, while anionic asphalt emulsion showed better workability than that prepared with the cationic asphalt emulsion [7]. Additionally, a high cement in cement-asphalt emulsion mixture leads to poor workability as well [9]. Adding cement particles in cement-asphalt emulsion mortar and cement-asphalt emulsion paste extends the setting time and has a significant effect on cement hydration retarding. Wang, Shu, Rutherford, Huang, and Clarke reported that anionic asphalt emulsion could delay cement hydration longer than cationic asphalt emulsion [7].

Cement-asphalt emulsion mixture with increasing asphalt emulsion to cement ratio, extending the initial and the final setting times showed that asphalt emulsion has a significant retarding effect on the cement hydration, which is relevant to the types of asphalt emulsion and its dosages. Besides, the hydration heat of the cement hydration process was delay [10-12].

The cement particle contributes to the hardening of cold asphalt mixtures both by creating cement paste bridges between the aggregates, and by removing water from the mixtures through cement hydration. The mixtures hardened faster when the amount of cement was increased [13].

The breaking asphalt emulsion or absorption asphalt droplets to cement grains in cement-asphalt emulsion mixture was accelerated by the cement. The cationic asphalt emulsion had a stronger absorption than anionic asphalt emulsion. The particle size increase was mainly attributed to the absorption behavior of asphalt droplets to cement grains. Moreover, cationic asphalt emulsion affects the increase in particle size than anionic asphalt emulsion, which led to a loss of flowability of cement-asphalt emulsion mixture [14].

Few studies in cement-asphalt emulsion mortar and cement-asphalt emulsion paste has been reported that asphalt emulsion to cement ratio had a significant influence on the strength and developing a process of cement-asphalt emulsion mixture [12]. Increasing cement content increases the indirect tensile strength of cement-asphalt emulsion mixture and decreases the optimum-asphalt emulsion content during cement-asphalt emulsion mixture design. Additionally, cement addition improves tensile strength, rutting resistance, and moisture susceptibility [15-16]. In contrast, flexural strength, compressive strength, CBR, uniaxial compressive strength (UCS), indirect tensile (IDT) strength, tensile strength ratio (TSR), and dynamic modulus fall by the increase of the asphalt emulsion content while the shrinkage increases when increasing asphalt emulsion content [17-19]. However, adding too much asphalt emulsion reduces strength [20]. Moreover, cationic asphalt emulsion in cement-asphalt emulsion mixture gives a higher shear modulus, a faster breaking of asphalt emulsion, higher compressive strength, and higher stiffness than anionic asphalt emulsion [7, 21].

Effects of temperature; Seref, Fazil, and Vefa found that high temperature causes deformation and lubrication, while the problems of low temperature are cracking and surface abrasion. Therefore, the deformation increases with a decreasing in cement addition of cement-asphalt emulsion mixture. The resistance to permanent deformation of cement-asphalt emulsion mixture was increased by the addition of cement. The resilient modulus of cement-asphalt emulsion mixtures increased with an increase in cement content. The resilient modulus decreases with decreasing temperature [21].

As known, curing humidity and curing temperature could affect to the strength development of any cement-based materials. A higher curing temperature significantly shortens the curing period. Curing humidity affects the strength development of any cement-based materials, especially for a higher relative humidity that can lead to a lower strength. Moreover, higher relative humidity reduces the interface bond between aggregates and cement-asphalt emulsion [22]. Cement-asphalt emulsion mixtures cured at a high relative humidity hardened slower than mixtures cured at a low relative humidity [13].

Xu, Huang, Qin, and Li reported that the more curing time and increase in cement content, the better indirect tensile strength value increased. The indirect tensile strength of the mixture without cement was lower than the mixture with cement, indicating that cement effectively enhanced the initial strength of the cement-asphalt emulsion mixtures. Increasing the cement content leads to better moisture resistant properties and a higher rate of increase in strength [9]. Cement-asphalt emulsion mixture with higher cement content showed the result in improved moisture damage resistance [15].

Also, the cement addition in cold mix asphalt concrete has higher stiffness because the deformability of the cement phase is lower than the deformability of the asphalt phase. Moreover, the cement improves the moisture resistance of the mixture, as cement creates a chemical bond between the aggregates. Cold mix asphalt concrete without cementitious additions was more sensitive to the environmental humidity than that with cement added [13].

Garcia, Lura, Partl, Jerjen, and Shaowen described that the hydration process of cement-asphalt emulsion mixture, the cement particles hydrate with the water phase of the asphalt emulsion when cement is added into asphalt emulsion. At the same time, asphalt droplets and cement particles come into contact due to intensive chemical adsorption. As a result, some cement particles are covered by an asphalt film, causing a delay hydration reaction process of cement. Moreover, adding cement improves dry tensile strength, rutting resistance, and moisture susceptibility [15].

An increase of the cement content also proportionally increases the number of hydration products formed and thereby the volume of cementitious bridges between aggregates and fillers [13].

Many researchers studied the microstructure of cement-asphalt emulsion mixtures. Cement and asphalt emulsion composite does not give a new binder or new crystalline substances. The microstructure of cement-asphalt emulsion showed the hydration product the needle-like ettringite structure and more porous than asphalt emulsion mixtures and cement mixtures [10, 15, 18, 23].

As mentioned in those research studies, many factors can affect the mechanical properties and rheological properties of cement-asphalt emulsion mixture such as the types of asphalt emulsion, the types of cement, relative humidity. However, there is no research study about the effects of the ratio between cement and asphalt emulsion. Therefore, this research performed at Chiang Mai University laboratory, Thailand. It is created to study the effect of cement-asphalt emulsion mortar by varying ratio of cement and asphalt emulsion, to determine the compressive strength and flexural strength of cement-asphalt emulsion mortar, and to recommend a proper ratio of cement and asphalt emulsion to be applied in Thailand pavement stabilization.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this research were prepared as test samples which consist of dried sand in accordance with ASTM C778 - 17 standard specifications for standard sand [24]. Portland cement type I was used as cementitious material because it is a general material for pavement stabilization in Thailand. The cationic asphalt emulsion (CSS-1) was used as a bituminous material because of its lower retardation effect of the hydration process than anionic asphalt emulsion.

2.2 Cement-asphalt Emulsion Ratios

Nine cement and asphalt emulsion ratios in this research were prepared at a fixed CAE mortar ratio. The materials were weighed for preparing three specimens for compressive strength test by adding a fixed weight of dried sand and water as shown in Table 1. While the materials for preparing three flexural test specimens were prepared as shown in Table 2.

Table 1 Cement asphalt emulsion ratios and materials preparation for compressive strength tests

Ratios (cement:asphalt emulsion)	Weight of additives (g.)			
	Cement	AE	Dried sand	water
1:0	255	0	700	123
4:1	204	51	700	123
3:1	191	64	700	123
2:1	170	85	700	123
1:1	127	127	700	123
1:2	85	170	700	123
1:3	64	191	700	123
1:4	51	204	700	123
0:1	0	255	700	123

Table 2 Cement asphalt emulsion ratios and materials preparation for flexural strength tests

Ratios (cement:asphalt emulsion)	Weight of additives (g.)			
	Cement	AE	Dried sand	water
1:0	582	0	1600	282
4:1	465	116	1600	282
3:1	436	145	1600	282
2:1	388	194	1600	282
1:1	291	291	1600	282
1:2	194	388	1600	282
1:3	145	436	1600	282
1:4	116	465	1600	282
0:1	0	582	1600	282

2.3 Methods

2.3.1 Compressive Strength Test

The sample preparation of compressive strength test consists of dried sand mixed with cement-asphalt emulsion in the ratio of sand: water: cement-asphalt emulsion (1.000: 0.176: 0.364) in according with ASTM C109 [25]. Each material was weighed as shown in Table 1 and mixed. Asphalt emulsion was mixed with dried sand before adding cement and additional water as a cement slurry form. Then, the mixtures were placed into cube molds (50mm × 50mm × 50mm) to be used as test specimens of compressive strength.

The specimens were cured in molds for 24 hours at ambient temperature and later sealed with plastic wraps to prevent moisture loss and kept in more than 50% relative humidity environment to reach 7 days and 28 days of curing. Curing at 50% humidity to make cement asphalt emulsion complete hydration and higher strength.

Before testing, the test specimens were measured their dimensions and weight. Then, the cube specimens were tested using the compressive strength testing machine as presented in Fig.1.

Fig. 1 The compressive strength testing

The compressive load was constantly applied to a test specimen until the failure occurs at a rate of loading of 1000 N/s. Then, the compressive strength can be determined based on Eq.(1) as follows:

$$f_m = P/A \quad (1)$$

Where; f_m is compressive strength [MPa.], P is the maximum compressive load [N], and A is the area of the loaded surface [mm^2].

2.3.2 Flexural Strength Test

The test specimens of the flexural strength test were prepared as the same mixtures ratio as compressive strength test specimens. Each material was weighed as shown in Table 2 and mixed. The mixtures were placed into prism molds (40mm × 40mm × 160mm). The specimens were cured in molds for 24 hours at ambient temperature and later sealed with plastic wraps to prevent moisture loss and kept in more than 50% relative humidity environment to reach 7 days and 28 days of curing. The prism specimens were tested by the three-point loading method to measure the flexural strength as illustrated in Fig.2.

Fig. 2 The three-point loading method

A prism specimen is on the supporting rollers. Then, the load was applied vertically at the center of a prism specimen at a rate of loading of 50 N/s and keep increasing it constantly up to the failure [26-27]. The flexural strength can be calculated using Eq.(2):

$$R_f = (1.5 \times F_f \times L) / b^3 \quad (2)$$

Where; R_f is the flexural strength [MPa], b is the side of the square section of the prism, [mm], F_f is the load applied to the middle of the prism at fracture [N], and L is the distance between the supports [mm].

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Test

The results of the compressive strength test are shown in Table 3. The CAE mortar with cement: asphalt emulsion ratio of 3:1 shows the highest compressive strength (5.71 MPa) at 7 days because of moisture from asphalt emulsion, and additional water effect to the hydration process resulting in high strength. However, the specimen with a ratio of 4:1 (cement: asphalt emulsion) has the highest compressive strength (8.63 MPa) at 28 days due to its full strength development. The asphalt emulsion mortar with a ratio of 0:1 (cement: asphalt emulsion) shows the lowest compressive strength at 28 days. It has slow strength development because of high water content. As shown in Fig. 3; additionally, its strength at 7 days is approximately 70% of the strength at the final curing time.

Table 3 Compressive strength of the specimens at 7 and 28 days of curing time

Ratio (cement:asphalt emulsion)	Compressive Strength 7 days (MPa)	Compressive Strength 28 days (Mpa)
1:0	3.56	4.73
4:1	4.02	8.63
3:1	5.71	8.20
2:1	5.15	6.45
1:1	1.83	2.31
1:2	0.65	0.92
1:3	0.40	0.64
1:4	0.20	0.38
0:1	0.14	0.16

The high asphalt emulsion ratio gives low strength, approximately 30% of the high cement ratio. The compressive strength decreases as asphalt emulsion increases. The results from the testing found in accordance with other research, the cement increasing can increase the strength of cement-asphalt emulsion mixture. On the other hand, the increasing of asphalt emulsion content decreases the compressive strength. A high asphalt emulsion content decreases the strength [16, 18-20].

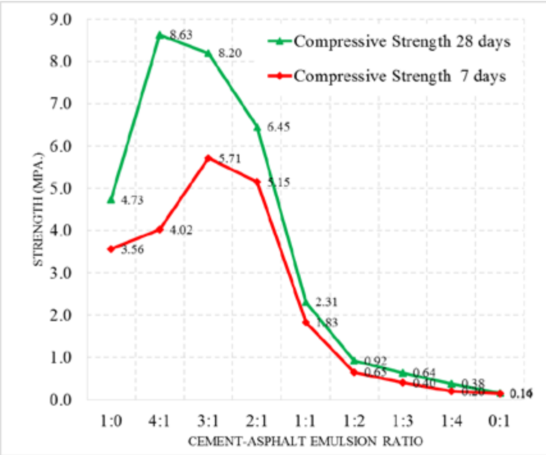

Fig.3 The results of compressive strength test

3.2 Flexural Strength Test

The results of the flexural strength test are shown in Table 4.

Table 4 Flexural strength of the specimens at 7 and 28 days of curing time

Ratio (cement:asphalt emulsion)	Flexural Strength 7 days (MPa)	Flexural Strength 28 days (MPa)
1:0	2.53	3.01
4:1	2.03	3.47
3:1	2.10	2.11
2:1	1.39	1.80
1:1	0.35	0.88
1:2	0.08	0.10
1:3	0.05	0.26
1:4	0.03	0.04
0:1	0.04	0.06

The CAE mortar ratio of 1:0 (cement: asphalt emulsion) presents the highest flexural strength (2.53 MPa) at 7 days, while the ratio of 4:1 (cement: asphalt emulsion) shows the highest flexural strength (3.47 MPa) at 28 days as shown in Fig. 4.

The values of flexural strength are less than compressive strength, approximately 30% of the values. The strength at 7 days is around 70% of the 28-day curing period.

At a fixed CAE mortar ratio, the flexural strength decreases by increasing asphalt emulsions. The high asphalt emulsion ratio gives low strength, approximately 20% of the high cement ratio. Moreover, flexural strength test results with high asphalt emulsion ratio were varied.

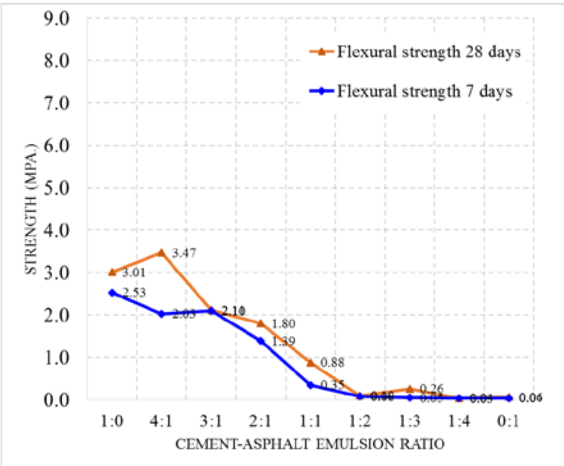

Fig.4 The results of flexural strength test

Refer to other research, the flexural strength of the mixture without cement or asphalt emulsion mixture was lower than the mixture with cement, indicating that cement effectively enhances the initial strength of the mixtures [9].

3.3 Compressive Strength and Flexural Strength of Asphalt Emulsion Mortar

The results of asphalt emulsion mortar with a ratio of 0:1 (cement: asphalt emulsion) and kept in more than 50% relative humidity during curing, failed with unmeasurable strength condition as shown in Fig. 5. Asphalt emulsion mortar was later prepared for an additional test in an uncontrolled relative humidity condition. The flexural strength and compressive strength at 28 days are 0.06 MPa and 0.16 MPa., respectively. The values are much lower than those of cement-asphalt emulsion mortar. It is caused by the high water content of asphalt emulsion mortar mixture (additional water and water in asphalt emulsion) which affects the specimen’s strength directly. Cement-asphalt emulsion mortar with a proper amount of additional water and water in asphalt emulsion occurred during the hydration process results in high strength.

According to other research, higher relative humidity can lead to lower strength because a higher relative humidity decreases the interface bond between aggregates and cement-asphalt emulsion [22]. In addition, the strength might be dropped by adding excessive asphalt emulsion [18-20].

Moreover, the mixture without cementitious addition was more sensitive to the environmental humidity than the mixture with cementitious. Cement-asphalt emulsion mixtures cured at a high relative humidity harden slower than mixtures cured at a low relative humidity [13].

Fig. 5 asphalt emulsion-mortar specimens failed

3.4 Recommended Ratio of Cement-asphalt Emulsion

The optimum ratio of cement-asphalt emulsion is considered from maximum strength. The mortar with a high asphalt emulsion content shows the low strength and unmeasurable strength, while the mortar with high cement content presented high strength. Especially, the strength cement-asphalt emulsion ratio 4:1 is higher than the cement mortar (ratio of 1:0). Moreover, the ratio of 4:1 (cement: asphalt emulsion) illustrates the highest flexural strength and the highest compressive strength at 28 days. A little asphalt emulsion addition, therefore, can improve waterproofing and strength in cement mortar.

The results from the testing found in accordance with other research. For example, the increase of cement increases the strength of cement-asphalt emulsion mixture **[**16**]**. In contrast, the increase of asphalt emulsion content decreases in flexural strength, compressive strength and CBR **[**18-19**]**. However, adding too much asphalt emulsion reduces strength **[**20**]**.

4. CONCLUSIONS

This research aims to investigate resulting from the mixture of cement and asphalt emulsion as a new stabilizing agent. This mixture provides more strength and waterproofing. The flexural strength and the compressive strength of cement-asphalt emulsion mortar decrease with an increase in asphalt emulsion and increase with an increase in cement (at fixed CAE mortar ratio). Moreover, adding too much of asphalt emulsion led to low strength because of high water from additional water and water in asphalt emulsion. The ratio of 4:1 (cement: asphalt emulsion) shows the highest compressive strength and flexural strength at 28 days because of the water from additional water and water in asphalt emulsion react with cement particle and the asphalt film by removing water from the mixtures through cement hydration as a bridge between the aggregates. As a result, the cement-asphalt emulsion mixture has higher strength than cement or emulsion mixture alone.

The initial setting time (7-days curing period) of cement-asphalt emulsion mixture is slower than cement mixture because some results present low strength. Nevertheless, the final setting time (28-days curing period) presented that cement-asphalt emulsion mixture higher strength than the cement mixture. These are effects from a high relative humidity curing and retardation effect from additional asphalt emulsion. Then, the curing specimen should be cured with low relative humidity.

Therefore, the cement-asphalt emulsion ratio of 4:1 is recommended for further study to develop the cement-asphalt mixture as a stabilizing agent for road base stabilization in the road and highway construction industry.

5. ACKNOWLEDGMENTS

The authors are thankful for use of the services and facilities of the Department of Civil Engineering, Faculty of Engineering Chiang Mai University. The first author received funding from the Graduate Research Scholarship for Fiscal Year 2018, funded by the Graduate School, Chiang Mai University.

6. REFERENCES

[1] Grogan W. P., Weiss, Jr. C. A. and Rollings R. S., "Stabilized base courses for advanced pavement design report 1: literature review and field performance data," U.S. Department of Transportation, Federal Aviation Administration, Washington, DC, 1999.

[2] Han M. and Lytton R., "Theoretical prediction of drying shrinkage of concrete," Journal of Materials in Civil Engineering, vol. 7, no. 4, pp. 204-207, 1995.

[3] Ouyang J., Hu L., Li H. and Han B., "Effect of cement on the demulsifying behavior of over-stabilized asphalt emulsion during mixing," Construction and Building Materials Vol.177, pp. 252-260, 2018.

[4] Li G., Zhao Y., Pang S.-S. and Huang W., "Experimental study of cement-asphalt emulsion composite," Cement and Concrete Research, Vol.28, No.5, pp. 635-641, 1998.

[5] Song H., Do J. and Soh Y., "Feasibility study of asphalt-modified mortars using asphalt emulsion," Construction and Building Materials Vol.20, pp. 332-337, 2006.

[6] Kong X.-m., Liu Y.-l., Zhang Y.-r., Zhang Z.-l., Yan P.-y. and Bai Y., "Influences of temperature on mechanical properties of cement asphalt mortars," Materials and Structures Vol.47, pp. 285-292, 2014.

[7] Wang Z., Shu X., Rutherford T., Huang B. and Clarke D., "Effects of asphalt emulsion on properties of fresh cement emulsified asphalt mortar," Construction and Building Materials Vol. 75, pp. 25-30, 2015.

[8] Zhang Y., Kong X., Hou S., Liu Y. and Han S., "Study on the rheological properties of fresh cement asphalt paste," Construction and Building Materials Vol.27, pp. 534-544, 2012.

[9] Xu J., Huang S., Qin Y. and Li F., "The Impact of Cement Contents on the Properties of Asphalt Emulsion Stabilized Cold Recycling Mixtures," International Journal of Pavement Research and Technology Vol.4 No.1, pp. 48-55, 2011.

[10] Li W., Hong J., Zhu X., Yang D., Bai Y. and Liu J., "Retardation mechanism of anionic asphalt emulsion on the hydration of Portland cement," Construction and Building Materials Vol.163, pp. 714-723, 2018.

[11] Tan Y., Ouyang J., Lv J. and Li Y., "Effect of emulsifier on cement hydration in cement asphalt mortar," Construction and Building Materials Vol.47, pp. 159-164, 2013.

[12] Wang Q., Yan P., Kong X. and Yang J., "Compressive Strength Development and Microstructure of Cement-asphalt Mortar," Journal of Wuhan University of Technology-Mater. Sci. Ed., pp. 998-1003, 2011.

[13] Garcia A., Lura P., Patel M. N. and Jerjen I., "Influence of cement content and environmental humidity on asphalt emulsion and cement composites performance," Material and Structures, 2012.

[14] Hu S., Wang T., Wang F., Liu Z. and Gao T., "Absorption behavior between cement and asphalt emulsion in CA mortar," Advances in Cement Research Vol.20 No.1, pp. 1-4, 2008.

[15] Shaowen D., "Interaction mechanism of cement and asphalt emulsion in asphalt emulsion mixtures," Materials and Structures, 2014.

[16] Han F. and Chen Z., "Analysis of Effect of Cement on Strength of Emulsified Asphalt Cold Recycled Mixture," in 1st International

Conference on Transportation Infrastructure and Materials (ICTIM 2016), Xian, China, 2016.

[17] Rutherford T., Wang Z., Shu X., Huang B. and Clarke D., "Laboratory investigation into mechanical properties of cement emulsified asphalt mortar," Construction and Building Materials Vol.65, pp. 76-83, 2014.

[18] Montepara A., "The Role of Cement in The Recycling of Asphalt Pavement Cold-Stabilized with Bituminous Emulsions," in 2nd International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control, Alabama, USA, 2001.

[19] Bondietti M., Murphy D., Jenkins K. and Burger R., "Research on The Stabilisation of Two Different Materials Using Bitumen Emulsion and Cement," in Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04), Sun City, South Africa, 2004.

[20] Du J. C., Kuo M.-F. and Yeh J., "Properties of Cement Asphalt Emulsion Mortar for Pavement," Advanced Materials Research Vol.723, pp. 466-473, 2013.

[21] Seref O., Fazil C. and Vefa A. M., "Effect of Cement on Emulsified Asphalt Mixtures," Journal of Materials Engineering and Performance, pp. 578-583, 2007.

[22] Shaowen D., "Effect of curing conditions on properties of cement asphalt emulsion mixtures," Construction and Building Materials Vol.164, pp. 84-93, 2018.

[23] Yao Y., "Performance and Microanalysis of Cement Asphalt Mortar with Admixture of Coal Fly Ash," Journal of Materials Science Research Vol.1 No.2, pp. 48-55, 2012.

[24] "ASTM C778-17, Standard Specification for Standard Sand," ASTM International, West Conshohocken, PA, 2017.

[25] "ASTM C109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)," ASTM International, United States, 2008.

[26] "BRITISH STANDARD BS EN 196-1:2005 Methods of testing cement Part 1: Determination of strength," Brussels, 2005.

[27] "ASTM C78/C78M-18 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)," ASTM International, West Conshohocken, PA, 2018.