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# A New Cold Recycling Method for Reclaimed Asphalt Pavement Towards Improved Engineering Performance

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## ABSTRACT

Cold recycling is a more environment-friendly way to recycle reclaimed asphalt pavement (RAP) compared with hot recycling. However, cold recycled mixtures in general have poorer mechanical performance and durability than hot recycled mixtures. This study aims to develop a new cold recycling method by collectively using multiple additives, including a recycling agent, an emulsifying agent, a modifier, water and cement, to improve the durability of cold recycled mixtures. To achieve this objective, hot mix asphalt (HMA) was prepared and aged in lab to produce RAP. Then, both the conventional method by using emulsified asphalt and the new method by using multiple additives were applied to produce cold recycled mixtures. Comprehensive laboratory tests, including splitting test, moisture damage resistance test, indirect tensile fatigue test, and immersion asphalt pavement analyzer (APA) test, were conducted to evaluate and compare the performances of various cold recycled mixtures. It was found that the new cold recycling method provided significantly better overall performance than the conventional method.

**KEYWORDS:** Reclaimed asphalt pavement; Aged asphalt; Cold-recycling; Dissolving; Emulsifying

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## 1 INTRODUCTION

Recycling of reclaimed asphalt pavement (RAP) is nowadays a common sustainable practice in pavement engineering, which saves virgin construction materials and construction costs without compromising the pavement performance. According to the working mechanism, the RAP recycling technologies can be divided into the following categories: hot in-plant recycling, hot in-place recycling, full depth reclamation, and cold recycling [1]. Two methods of cold recycling are central plant recycling and cold in-place recycling. Cold recycling is usually conducted by mixing crushed RAP, recycling agents, and water without heating. Thus, it costs less energy and produces less emission during construction. Currently, the most commonly used recycling agents are emulsified asphalt with cement and foamed asphalt with cement. Other agent choices include softer asphalt, cutback asphalt, and combinations of emulsions with cement, fly ash, or lime. Various asphalt binders have been used for cold mix recycling, such as cationic, anionic or high-float medium-setting emulsions, or their polymer-modified versions. When foamed asphalt is used, small amount (1%-1.5%) of lime or cement is commonly added to increase its initial strength and resistance to water damage [2-5].

To take better advantage of the aged RAP binder when producing the recycled mix, a recycling agent is commonly used to restore its properties during recycling. Recycling agents are usually organic materials with chemical and physical characteristics selected to restore the aged binder according to the desired specifications. These agents can be generally divided into softening and rejuvenating agents. Softening agents lower the viscosity of the aged binder while rejuvenating agents restore its physical and chemical properties. Examples of softening agents include flux oil, slurry oil, and soft bitumen, while rejuvenating agents mainly include lubricating and extender oils, which contain high proportions of maltenes [6-10] One important criterion for selecting the rejuvenating agent is its compatibility with the aged binder. Rejuvenating agents with low saturate content and high aromatic content are usually compatible with aged binder [11, 12]. The choice of recycling agent is dependent on the time and temperature needed for the interaction between the recycling agent and the aged asphalt. However, the interaction mechanism between the recycling agent and the aged asphalt binder has not been fully understood yet. Various studies have been conducted on whether the aged asphalt acts as a binder or largely as part of the aggregate [13-16]. A concept of effective asphalt content, which consists of new and recycled asphalt, has been utilized to predict the ultimate performance of the mix. But the best way to ensure the quality of the recycled mix is to directly measure the mechanical properties of the recycled mix prepared with selected type and amount of recycling agent [17-19].

The main objective of this study is to develop a new cold recycling method to recycle RAP into a base mix and validate its engineering performance. This new cold recycling method is based on collectively using water and multiple additives, including a recycling agent, an emulsifying agent, cement, and a modifier. The motivations of using these additives are to dissolve aged asphalt, reduce the interface friction between the recycling agent and water, enhance the initial strength of the recycled mix, and improve the engineering performance of the recycled mix. To achieve this objective, the following research tasks were conducted:

1. Selecting appropriate recycling agent and additives for the new cold recycling method;
2. Preparing cold recycled mixes using both the new method and the conventional method;
3. Characterizing and comparing the engineering performances, especially the moisture damage resistance and fatigue cracking resistance, of the cold recycled mixtures prepared by the new and conventional methods.

## 2 TESTING MATERIALS

### 2.1 RAP

In this study, an AC-20 mixture with an asphalt-aggregate ratio of 4.3% was aged in lab to produce RAP. The loose AC-20 mixture was first conditioned in an oven at 135℃ for 4 hours and stirring of the mix was conducted once per hour. Then the aged mix was further conditioned at 85℃ for 120 hours [20]. Table 1 presents the properties of the aged asphalt extracted from the lab prepared RAP. Figure 1 shows the aggregate gradation of RAP after ignition.

**TABLE 1. Properties of aged asphalt**

| Age asphalt after extraction | Results |
|---|---|
| Penetration in 25℃ / 0.1mm | 25 |
| Softening point / ℃ | 65 |
| Ductility in 15℃ / cm | 3.5 |

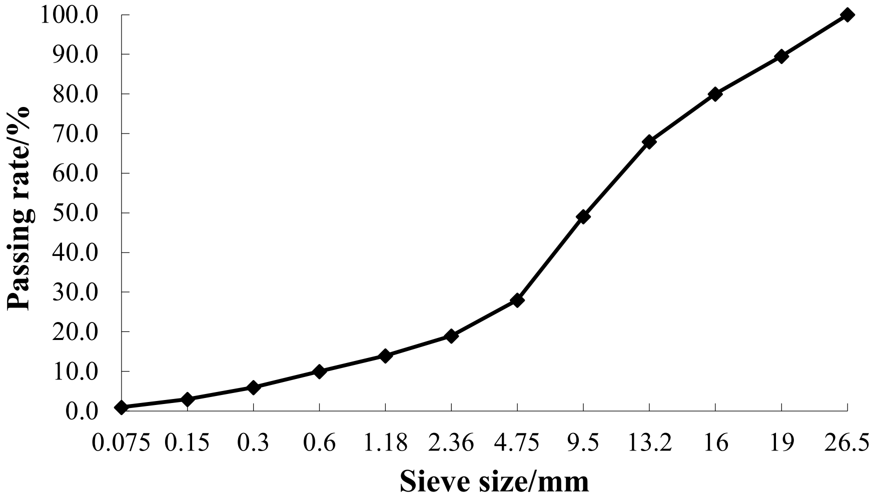


**FIGURE 1 Gradation of the mix after ignition**

## 2.2 Recycling Agent

Ageing of asphalt mixtures include both reversible and irreversible portions. In irreversible ageing, the chemical changes in asphalt are irrecoverable unless it is blended with modifiers or rejuvenators. Adding a recycling agent is usually the most effective way to recycle asphalt, which compensates for the decrease in the amount of the small molecular fractions (saturates and aromatics). Therefore, aromatics are the common fractions among various recycling agents. Based on the results of preliminary trial tests, dimethylbenzene (p-Xylene) was chosen in this study as the rejuvenating agent. dimethylbenzene is a slightly greasy, colorless liquid commonly encountered as a solvent. It represents about 0.5–1% of crude oil (depending on the source).

### 2.3 Emulsifying Agent

Emulsifying agents have both hydrophilic and lipophilic properties. They can be absorbed and concentrated at the oil-water interface to provide a protective barrier around the dispersed droplets. Because water is added into cold recycled mixtures to improve its workability and achieve maximum dry density, emulsifying agent was used to reduce the interfacial tension of dimethylbenzene and water. Moreover, the addition of the emulsifying agent could contribute to better coating of aggregate. Most asphalt used in asphalt pavement is petroleum asphalt, which contains the anion components, such as asphalt anhydride and asphalt acid. Therefore, cationic emulsifier is commonly used to emulsify asphalt. In consideration of its relatively low cost and environmental benefits, lignin amine type slow-break cationic emulsifier from the waste of paper making industry was selected as the emulsifying agent in this study.

### 2.4 Cement

In the cold recycling method using emulsified asphalt, cement is commonly used to increase the initial strength of the recycled mixtures and modify the interface bonding performance between asphalt and aggregate. In this study, 1.5 % Portland cement of No.32.5 by weight of the mixture was added to achieve the same purpose.

### 2.5 Modifier

In the mixing process of cement concrete, various polymer modifiers are added to increase the toughness, bonding and bending performance of cement concrete. Moreover, air voids in the cement mortar could be reduced and cohesive performance between the aggregate and cement mortar could be modified with the addition of polymer emulsion [21, 22]. In this study, the acrylic copolymer emulsion was added into the recycled mixtures as a modifier after the RAP was mixed with the recycling agent. During the mixing process, the modifier would be distributed within the recycled mixtures. After the addition of the Portland cement, the effect of cement hydration would gather the distributed acrylic copolymer emulsion and make it form silk or net like structure within mixtures. Moreover, it was reported that the addition of the polymer emulsion would lower the air voids, reduce the stress concentration effect and increase the toughness of the cement-treated mixtures [22].

### 2.6 Emulsified Asphalt

To compare the new recycling method with the conventional method using emulsified asphalt, a cationic slow-set emulsified asphalt was used in this study to prepare the cold recycled mixture as a Control Mix following the conventional method. The properties of the emulsified asphalt are shown in Table 2.

**TABLE 2 Properties of emulsified asphalt**

| **Technical indexes** | **Results** |
|---|---|
| Sieve residues/% | 0.03 |
| Saybolt Furol viscosity at 25°C$V_s$/s | 85 |
| Residue after evaporation / % | 58 |
| Technical performances of residue after evaporation | |
| Penetration at 25°C/0.1mm | 185 |
| Softening point/°C | 45 |
| Ductility at 15°C/cm | 45 |
| Solubility in Trichloroethylene/% | 98.5 |

### 2.7 Matrix for Cold Recycled Mixtures

To minimize the additional cost caused by using multiple additives, the total content of the emulsifying agent and modifier was kept at 0.15%. The costs of the recycling agent, emulsifying agent and modifier were approximately 1500 USD/ton, 5703 USD/ton, and

1681 USD/ton, respectively. To evaluate the influence of each agent on the mechanical performance of the recycled mixtures, various percentages of emulsifying agent and modifier were considered. The water content was determined by the maximum dry density test. Table 3 shows the matrix for the cold recycled mixtures prepared in this study.

**TABLE 3 Matrix for cold recycled mixtures**

| Mixture ID | Recycling agent content | Emulsifying agent content | Modifier content | Emulsified asphalt content | Water content |
|---|---|---|---|---|---|
| Mix 1 | 1.5% | 0.15% | 0 | - | 3.0% |
| Mix 2 | 1.5% | 0.10% | 0.05% | - | 3.0% |
| Mix 3 | 1.5% | 0.05% | 0.10% | - | 3.0% |
| Mix 4 | 1.5% | 0 | 0.15% | - | 2.8% |
| Control Mix | - | - | - | 4.0% | 2.5% |

## 3 EXPERIMENTAL PROGRAM

### 3.1 Sample Preparation and Curing

To prepare cold recycled mix using the new method, the following procedure as illustrated in Fig. 2 was followed: 1) adding recycling agent and blending it with RAP for 3 minutes; 2) adding emulsifying agent, modifier (if it was used), and water, and mixing them with the RAP for 2 minutes; and 3) adding cement and mixing it with RAP for 1.5 minutes.

**(a)** **(b)**


**FIGURE 2 Preparation of the cold recycled mixture: (a) RAP; (b) RAP after adding recycling agent; (c) RAP after adding recycling agent, emulsifying agent, and modifier; and (d) RAP after adding recycling agent, emulsifying agent, modifier, and cement.**

After the cold recycled mixtures were prepared, Marshall compaction was applied to prepare the samples with 75 double-sided blows. In order to accelerate the curing process and gain higher initial strength, the curing time and temperature were studied to determine the appropriate curing method.

### 3.2 Splitting Test

To evaluate the moisture damage resistance of the cold recycled mixture, two groups of samples were prepared for the splitting tests following the JTJ E20-2011[20], which were conducted at 15 ℃ with a loading rate of 50 mm/min. The first group of samples were conditioned at 15 ℃ for under dry condition. The second group of samples were tested after the following conditioning process: saturation in a water bath at 25 ℃ for 23 hours followed by saturation in a water bath at 15 ℃ for 1 hour.

To evaluate the freeze-thaw resistance of the cold recycled mixture, another two groups of samples were prepared for the splitting tests, which were conducted at 25 ℃ with a loading rate of 50 mm/min. The first group of samples were conditioned at 25 ℃ for under dry condition. The second group of samples were tested after the following conditioning process: storage in a fridge at -18ºC for 16 hours followed by immersion in a 60ºC water bath for 24 hours and conditioning at 25 ℃ for at least two hours under dry condition. The freeze-thaw splitting strength ratio was calculated as follows.

$$\mathrm{TSR} = \frac{R_{T2}}{R_{T1}} \times 100\% \tag{1}$$

where

TSR is Freeze-thaw strength ratio, %

$R_{T1}$ is strength without freeze and thaw, MPa

$R_{T2}$ is strength after freeze and thaw, MPa

### 3.3 Indirect Tensile Strength (IDTS) Test

The indirect tensile strength test was conducted to evaluate the fracture energy of the recycled mixtures. The IDTS test following the ASTM D6931-12 were performed at constant rate of 50.8 mm/min and temperature of 20℃[23]. The fracture energy was calculated from the area under force-deformation curve up to maximum failure load [24]. Fig. 3 represents fracture energy curve and the fracture energy can be divided according to the following equation:

$$W_T = W_D + W_S \quad (2)$$

Where $W_D$ is dissipated energy and $W_S$ is Strain energy. The typical force-deformation curve was shown in Fig 3.

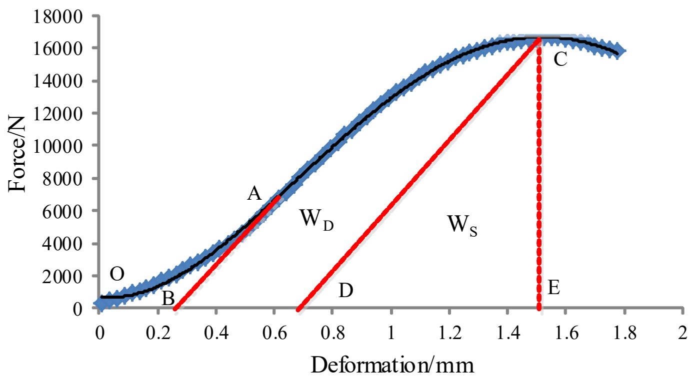


**FIGURE 3 Fracture energy from IDTS test**

The applied force started from 0N until it reached its maximum at point C, therefore the area under OCE represented the external energy, $W_T$. The corresponding Force-Deformation curve was fitted using the polynomial equation: $y = ax^4 + bx^3 + cx^2 + dx + e$. The counterpart displacement of the applied force can be extrapolated from point $x_c$. Consequently, the integral area from point $x_0$ to point $x_C$ gives the external energy, $W_T$,

$$W = A = \int_{x_0}^{x_C} f(x)dx \tag{3}$$

The external energy can be separated into the elastic strain energy and the dissipated energy. Therefore, the area of triangle *CDE,* represented as $W_s$, gives the stored elastic strain energy. Likewise, the area of $W_D$ gives the dissipated energy. A detailed explanation of how the dissipated energy, $W_D$, was calculated follows.

First, the inflection point of the force-displacement curve was determined as point *A*. Next, the X-coordinate of point *A* was calculated and denoted as $x_A$.

$$x_A = \frac{-3b - \sqrt{9b^2 - 24ac}}{12a} \tag{4}$$

A tangent line through point A has been drawn and designated as line AB. The slope, k, of line AB was calculated.

$$k = 4ax_A^3 + 3bx_A^2 + 2cx_A + d \tag{5}$$

According to Figure 3, point C is the highest point on the force displacement curve. The coordinates of point C were found using geometrical methods. A line through point C parallel to line AB gives the intersection of the X-axis at point D. The X-coordinate of point D and the Y-coordinate of point C were used to calculate the area of triangle CDE—this gives the stored elastic strain energy, Ws, see Figure 3. The computation of the dissipated energy, $W_D$, is now obvious.

### 3.4 Indirect Tensile Fatigue Test

The indirect tensile fatigue (IDTF) test was conducted using a material testing system (MTS). An environmental chamber was used to maintain the temperature of the samples at 15ºC. Prior to testing, the sample was placed into the chamber at the testing temperature for at least two hours for conditioning. The tests were performed under stress-controlled modes at 4 stress ratios (0.3, 0.5, 0.5 and 0.6). The stress ratio refers to ratio of applied the stress and the strength. A sinusoidal waveform was applied in the fatigue tests at frequency of 10 Hz. Failure of a sample tested is defined when localization of the micro cracks occurs.

### 3.5 Immersion Asphalt Pavement Analyzer Test

The immersion Asphalt Pavement Analyzer (APA) is a type of loaded wheel test, which is able to characterize the rutting resistance, moisture susceptibility, and fatigue cracking resistance of the testing specimen. In this study, the fatigue properties of the saturated cold recycled mixtures were evaluated. As Fig. 4 shows, rectangular samples with a size of 300 mm x 125 mm x 75 mm were prepared [24] and tested under a loading level of 1113N applied by pneumatic tubes. The beam samples were immersed in water at 15℃ during the test. The failure of the samples was caused by the combined effect of moisture and fatigue damage. Specimens' fatigue life was defined as the number of loading cycles, at which the beam breaks or the deflection rate of change (ROC) exceeds 1.0 mm/stroke [25].

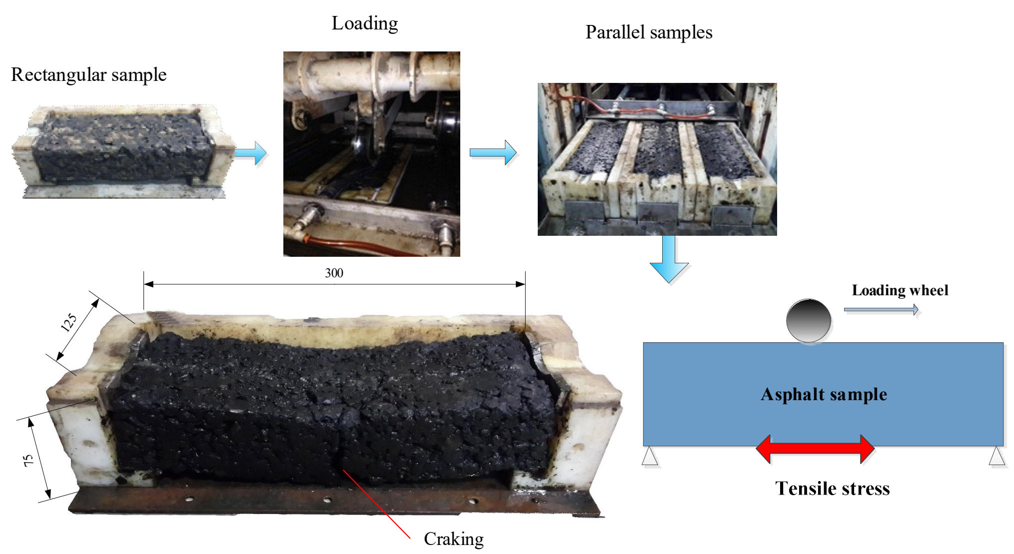


**FIGURE4 Immersed APA fatigue test (unit: mm)**

## 4 TEST RESULTS AND DISCUSSION

### 4.1 Curing Condition

In the cold mix recycling process, the curing condition for the recycled mixtures has significant effect on the initial strength of the samples. With the increase of the curing time, the strength of the recycled mixtures increases. The recycling agent and water in the cold recycled mixtures reduce the interface adhesion and mastic cohesion strength. Therefore, the weight loss of the Marshall samples before demoulding and their splitting strength after demoulding were monitored at different curing times. The splitting strength of Mix 1 was evaluated at different curing days at 60℃. The results are shown in Table 4.

**TABLE 4 Influence of curing time on cold recycled mixture**

| Curing days and temperature | Weight loss (%) | Splitting strength(MPa) |
|---|---|---|
| 60°C, 1d | 1 | 0.873 |
| 60°C, 2d | 0.4 | 1.202 |
| 60°C, 3d | 0.2 | 1.547 |
| 60°C, 4d | 0.05 | 1.558 |

From Table 4, it can be seen that the weights of the samples reduced obviously while their splitting strengths increased dramatically during the first 2 days. When the curing time reached 4 days, the weight loss and splitting strength became insignificant. Therefore, 3 days were selected as the time of demoulding in this study.

## 4.2 Volumetric Properties

Table 5 presents the volumetric properties of the Marshall samples with different recycling methods after curing.

**TABLE 5 Volumetric properties of cold recycled mixtures**

| Mixture ID | $G_{mm}$(g/cm$^3$) | $G_{mb}$ (g/cm$^3$) | Air void (%) |
|---|---|---|---|
| Mix 1 | 2.7155 | 2.4443 | 10.035 |
| Mix 2 | 2.6991 | 2.4575 | 8.951 |
| Mix 3 | 2.6918 | 2.4561 | 8.756 |
| Mix 4 | 2.6900 | 2.4796 | 7.821 |
| Control Mix | 2.4768 | 2.1783 | 12.050 |

It can be seen that the air void contents of Mix 2, Mix 3 and Mix 4 are much lower than those of the other two mixtures, indicating that the cold recycled mixtures with recycling agent, emulsified agent and modifier are easier to compact than those prepared with the Control Mix. Moreover, as the percentage of modifier increases, the air void content of the recycled mixtures decreases, indicating that the addition of acrylic copolymer emulsion could reduce the air void contents of the cold recycled mixtures

### 4.3 Splitting Test Results

Fig. 5 shows the results of the splitting tests. It can be seen that the dry and wet splitting strengths of Mix 1, Mix 2 Mix 3 and Mix 4 are all above 1 MPa and larger than that of the Control Mix. In addition, the splitting strength of Mix 4 is significantly lower than those of Mix 1, Mix2 and Mix 3, indicating that the addition of the emulsifying agent contributed to the increase of splitting strength. As the percentage of emulsifying agent decreases, the splitting strength slightly decreases too, implying that it is necessary to add emulsifying agent but its amount should be controlled.

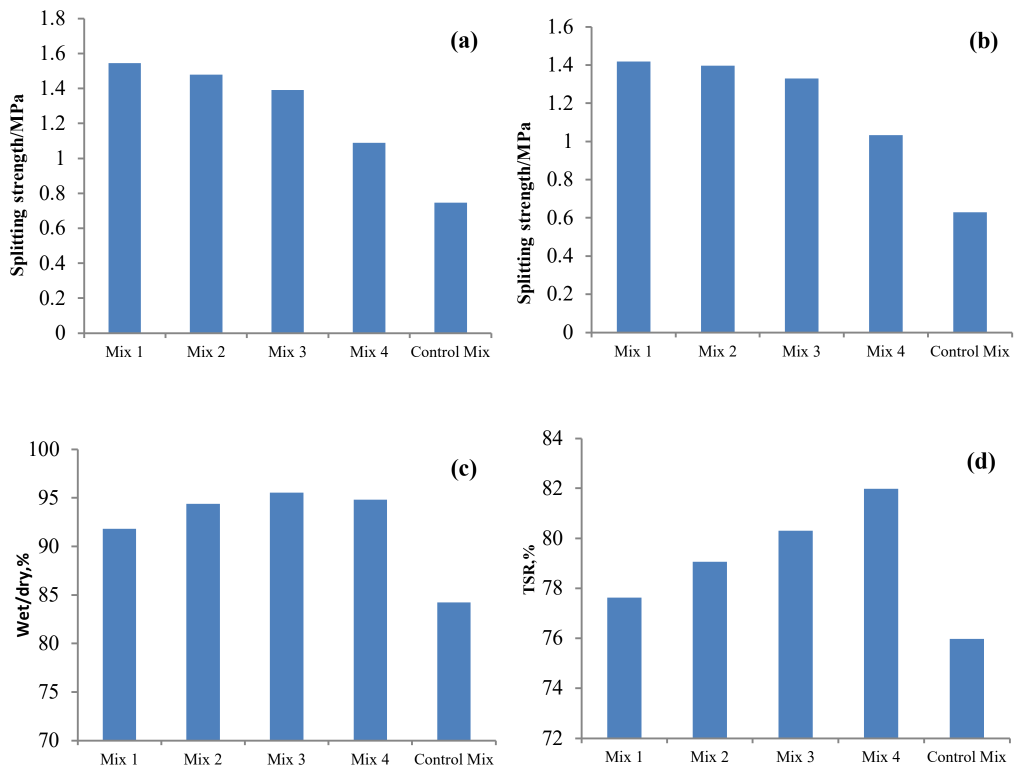


**FIGURE 5 Results of splitting test: (a) Splitting strength under dry condition; (b) Splitting strength after moisture conditioning; (c) Tensile strength ratio between dry and**

**wet splitting strengths; and (d) Tensile strength ratio between dray and freeze-thaw strengths.**

From Fig. 5(c) and Fig. 5(d), it can be observed that the new cold recycling method provides better resistance to moisture damage and freeze-thaw than the Control Mix. When the new cold recycling method is used, the addition of modifier improves the resistance to moisture damage of cold recycled mixtures.

### 4.4 IDT Fracture Energy

The average fracture energies of different cold recycled mixtures are shown in Fig. 6. It is obvious that the fracture energies of the recycled mixtures with the new cold recycling method are higher than that of the recycled mixtures with the Control Mix. Mix 2 had the highest fracture energy and elastic strain energy, followed by Mix 3. This indicates that the combined use of emulsified agent and modifier provides cold recycled mixtures better cracking resistance.

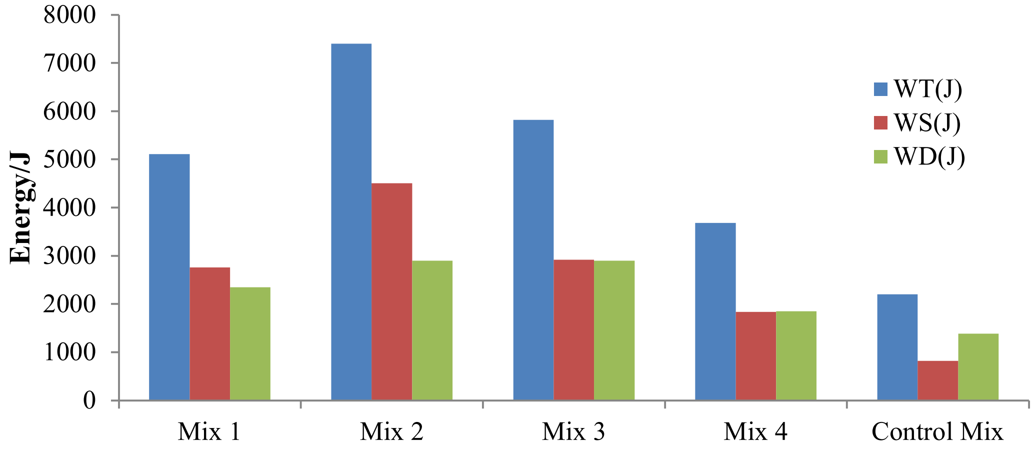


**FIGURE 6 Results of Energy composition**

### 4.5 Results of IDTF Tests

Fig. 6 and Fig. 7 present the IDTF test results at low and high stress levels, respectively. These results indicate that the new cold recycling method could provide longer fatigue life for cold recycled mixtures than the Control one. The fatigue life at low and high stress ratios presented different trend. It is commonly recognized that the lower stress ratio could provide a longer fatigue life. At low stress ratio levels, Mix 2, Mix 3 and Mix 4 provide slightly longer fatigue lives than Mix 1. The increasing percentage of the modifier slightly increases fatigue life. At high stress ratio levels, Mix 2 and Mix 4 had longer fatigue lives than the other cold recycled mixtures. Mix 4, which has the lowest air void content, provides the longest fatigue life. Therefore, the addition of modifier is believed to increase the fatigue life of the recycled mixtures.

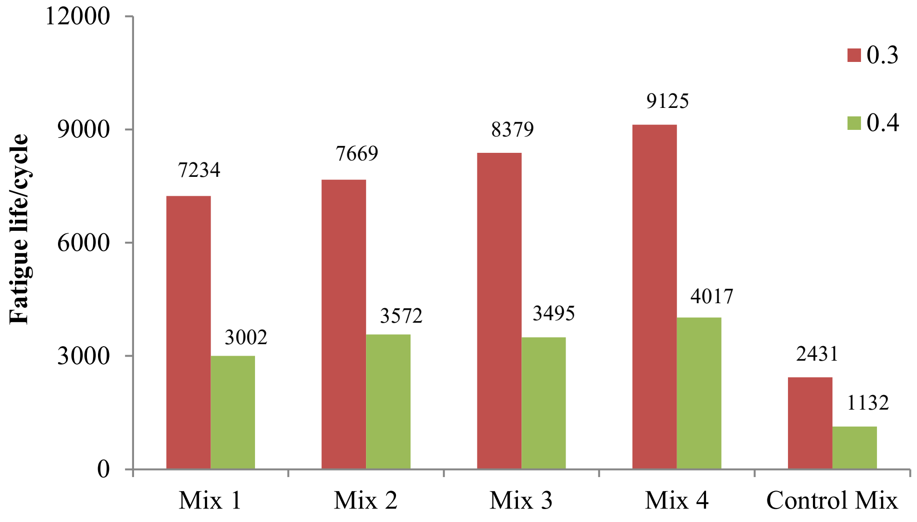


**FIGURE 7 Fatigue life of each mix at low stress ratios**

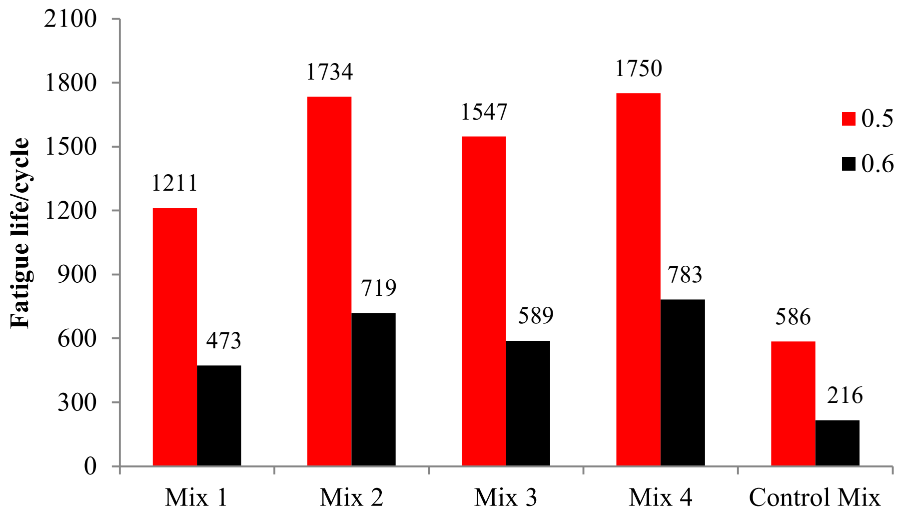


**FIGURE 8 Fatigue life of each mix at high stress ratio**

## 4.6 Immersion APA Test Results

Figures 9 to 11 present the deformation curves, fatigue lives, and vertical deformations at failure of each recycled mixture, respectively. The vertical deformation evolutions under repeated load can be divided into two stages: a slow increase in the first stage and a sharp increase in the second stage. All mixture recycled with the new method provide longer immersion fatigue life than that prepared with the Control Mix. Mix 2, Mix 3 and Mix 4(with modifiers) provide longer fatigue lives than Mix 1 (with emulsifying agent only). The immersion fatigue life of Mix 2 is the longest, which is consistent with the finding of the IDTF test at high stress ratios. But a higher percentage of modifier does not correspond to a longer immersion fatigue life. Considering the results of immersion APA tests and the IDTF tests, it is helpful to use modifier, but its dosage should be controlled.

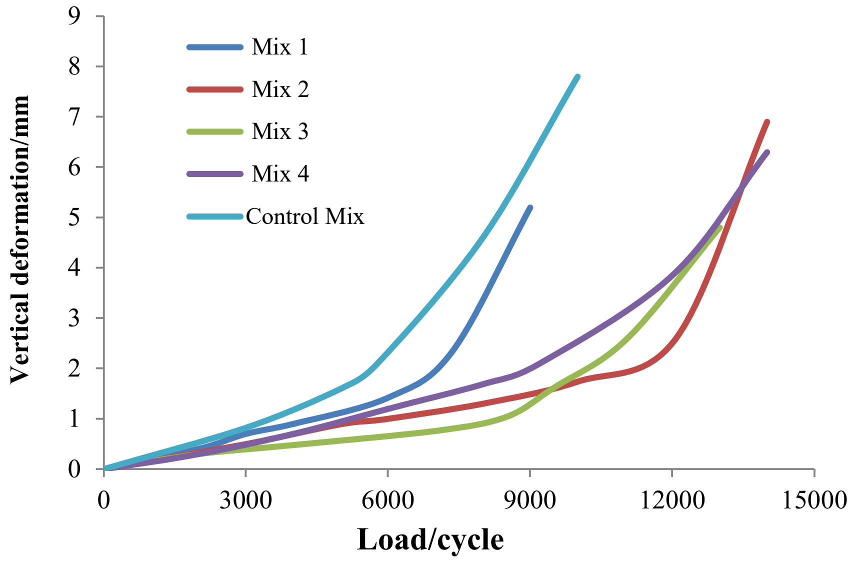


**FIGURE 9 Deformation curves of each recycled mixture**

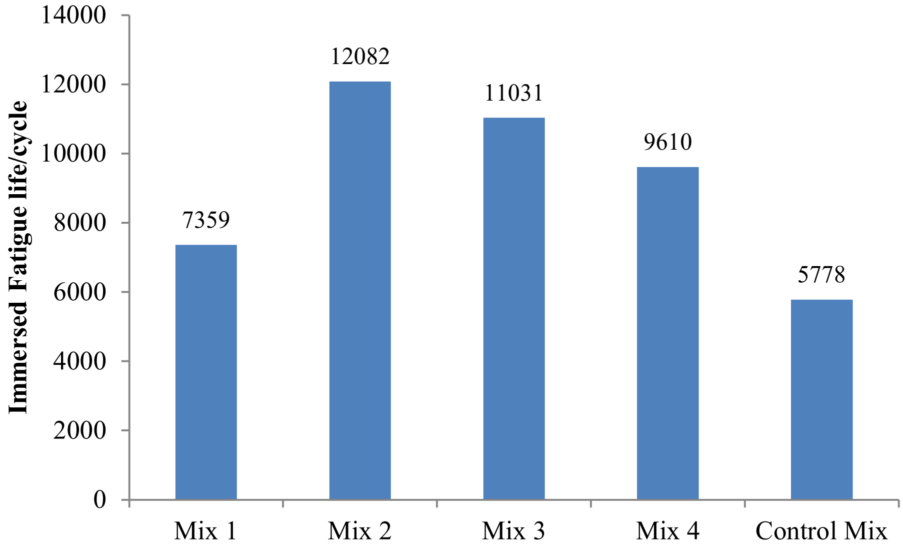


**FIGURE 10 Fatigue lives of each recycled mixture**

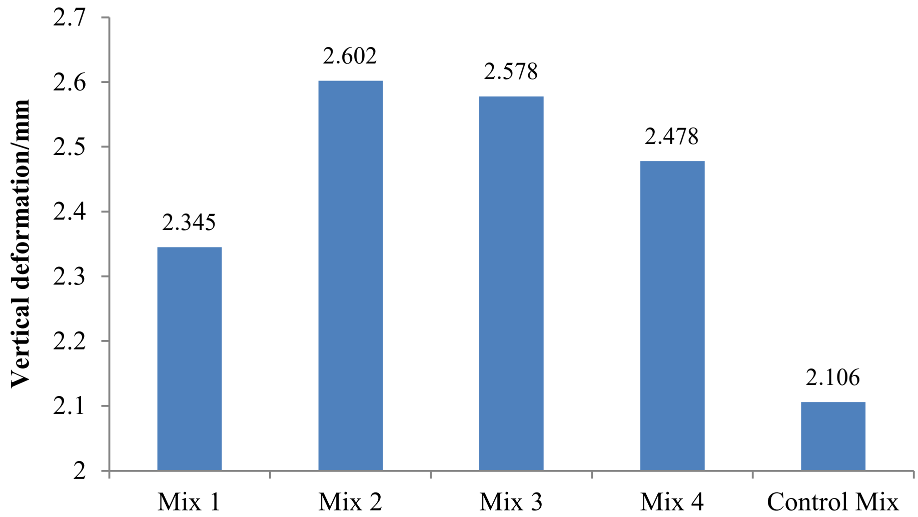


**FIGURE 11 Vertical deformations at failure of each recycled mixture**

## 5 FINDINGS AND RECOMMENDATIONS

This paper presents a new method for the cold recycling of aged asphalt mixture. The following points summarize the major findings of this study:

- The new cold recycling method provides the cold recycled mixtures better splitting strength, resistance to moisture and fatigue performance than the Control Mix using emulsified asphalt and cement.
- The recommended curing condition of the cold recycled mixtures for the new

method is 60℃ under dray condition for 3 days.

- When the new cold recycling method is used, Mix 2 with 1.5% recycling agent, 0.1% emulsifying agent and 0.05% modifier provide the optimum overall performance.
- The use of acrylic copolymer emulsion as a modifier is effective in reducing the air void content and improving the moisture damage resistance of the cold recycled mixtures.

This study has proved the benefits of using the new cold recycling method on the engineering performance of cold recycled mixtures in the laboratory. Further studies are recommended to quantify the life-cycle cost-effectiveness of the new method and investigate its field application and performance.

## REFERENCES


1. Asphalt Handbook, 7th Edition, 2007.
2. Kim, Y., H. Lee. Measurements of Moisture Conditions of Cold In-Place Recycling Layer. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.
3. Lane, B., T. Kazmierowski. Implementation of Cold In-Place Recycling with Expanded Asphalt Technology in Canada. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1905,* Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 17–24.
4. Morian, D. A., J. Oswalt, and A. Deodhar. Experience with Cold In-Place Recycling as a Reflective Crack Control Technique: Twenty Years Later. In Transportation Research Record: Journal of the Transportation Research Board, No. 1869, Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 47–55. Cold-recycled Bituminous Concrete using Bituminous Materials. Mix Design. N.C.H.R.P. Synthesis of Highway Practice, No.160, TRB, 1990.
5. T. K. Stone, Progress Report: Pacific Coast User-Producer Committee to Develop Specifications for Asphalt Recycling Agents, Minutes of the Fifteenth Pacific Coast Conference on Asphalt Specifications (May 1978).

6. Kari, W J. Prototype Specifications for Recycling Agents Used in Hot-Mixed Recycling. Association of Asphalt Pavement Technologists. 1980, pp. 177-199.
7. Shen, J.N, S. Amirkhanian, B.M. Tang. Effects of rejuvenator on performance-based properties of rejuvanted asphalt binder and mixtures. Construction and Building Materials (2007): 958-975
8. Shen, J.N, Serji Amirkhanian , J. A. Miller. Effects of Rejuvenating Agents on Superpave Mixtures Containing Reclaimed Asphalt Pavement. Journal of Materials in Civil Engineering (2007).
9. Karen A. O'Sullivan. Rejuvenation of Reclaimed Asphalt Pavement (RAP) in Hot Mix Asphalt Recycling with High RAP Content. A Thesis Submitted to the Faculty of the Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering, April 2011.
10. Chen J.Y., Experimental Study on Recycling Methods of Asphalt Pavements. Thesis submitted to the Dalian University of Technology for the degree of Doctor of Philosophy, May, 2011.
11. Zhou Z.G., Yang Y.P., Zhang Q.P., Recycling behavior of recycling agent on aged asphalt., Journal of Traffic and Transportation Engineering. Vol.11, No.6., Dec.2011.
12. Sebaaly, P. E., G. Bazi, E. Hitti, D. Weitzel, and S. Bemanian. Performance of Cold In-Place Recycling in Nevada. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1896,* Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 162–169.
13. Romanoschi, S. A., M. Hossain, A. Gisi, M. Heitzman. Accelerated Pavement Testing Evaluation of the Structural Contribution of Full-Depth Reclamation Material Stabilized with Foamed Asphalt. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1896,* Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 199-207.
14. Peterson,R.L., Soleymani, H.R., Anderson, R.M.&Mcdaniel, R.S.Year. Recovery and testing of RAP binders from recycled asphalt pavements. In: Association of Asphalt Paving Technologies Pro,2000

15. P. S. Lin, T.Lin Wu, C.W Chang , B.Y. Chou., Effects of recycling agents on aged asphalt binders and reclaimed asphalt concrete., Materials and Structures (2011) 44:911–921.
16. Hilbrich, S. L., and T. Scullion. Evaluation of Laboratory Mix Design and Field Performance of Asphalt Emulsion and Cement Stabilized Full-Depth Reclamation Project in Texas. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
17. Berthelot, C., R. Haichert, D. Podborochynski, C. Wandzura, B. Taylor, and D. Guenther. Mechanistic Laboratory Evaluation and Field Construction of Recycled Concrete Materials for Use in Road Substructures. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2167,* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 41–52.
18. Peter E. Sebaaly, Gabriel Bazi, Edgard Hitti, Dean Weitzel, Sohila Bemanian, Performance of Cold In-Place Recycling in Nevada, In *Transportation Research Record: Journal of the Transportation Research Board, No. 1896*, TRB, National Research Council, Washington, D.C., 2004, pp. 162-169.
19. Shen JN, Amirkhanian SJ, Tang B.M (2007) Effects of rejuvenator on performance-based properties of rejuvenated asphalt binder and mixtures. Constr Build Mater 21:958–964. doi:10.1016/j.conbuildmat.2006.03.006
20. Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering, JTG E20-2011.
21. Xu Y.J, Li X.C, Wong T.Y., Jin R.G., Study on blend system of styrene-acrylic ester copolymeric emulsion and cement mortar., Journal of BeiJing University of Chemical Technology., Vol. 25 ,No. 4,1998.
22. Shi D.M., performances and Applications of High Strength polymer Modified Cement mortar, Thesis submitted to the Wu Han University of Technology for the degree of Master of Philosophy, May, 2011.
23. ASTM D 6931 Standard - Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures.
24. Asphalt Vibratory Compactor (AVC) User's Guide, Pavement Technology

Inc.(PTI).

25. Asphalt Pavement Analyzer (APA) User’s Guide, Pavement Technology [S]. INC.