CHAPTER III

PROCEDURE OF STUDY

3.1 Advantages of Cold Deep In-Place Recycling

1. The construction of cement/asphalt recycled base increases strength of road structure as the cement/asphalt mixes into the waste of base course during road reconstruction. Cement treated base/asphalt treated base can better support heavier loads.
2. Cement treated/asphalt treated base better reduces the stress and strain than a gravel base, thus extending the period of road wear. Base construction by a cold deep in-place recycling technique reduces the new overlay, which shouldn't extend on a road shoulder to maintain geometric feature.
3. When constructing asphalt concrete surface on a cement/asphalt recycled base, the wheel strain is less than with a gravel base.
4. When constructing a full wide road surface using a cement/asphalt recycle base, the shoulder strength is stronger and motor cycles can pass smoothly and safely. Further more, an overlay surface on the shoulder is unnecessary even while durability is expected.
5. Cold deep in-place recycle base construction reduces the effect to people as it can be completed quickly with minimal as well as with reduced noise and dust during construction.
6. Cold deep in-place recycling means longer period between maintenance by recycling means lower construction than with surface overlay or base and sub-base construction.
7. This technique reduces the materials movement from source or stock materials area to real work site. Transport trucks carry loads of 30-45 tons which adversely affects road structure and reduce road life more quickly.

3.2 Disadvantages of Cold Deep In-Place Recycling

1. Soft spots on road surface should be solved before in-place recycling. If spots aren't corrected first, problems will arise more quickly after recycling.
2. Uniformity of materials of recycled base are not consistent. Therefore, the engineer in-charge must remain attentive. When he sees materials changes, he must order modifications immediately.
3. Depth of recycling base is 20 to 25 cm so compaction should be performed with quality compactor. Compaction of cement/asphalt treated base is more difficult than gravel or crush stone base in the quality of compactors should be tested in sections of 50 to 100 m. The density of base course and depth level must be checked to assure they meet requirements.

3.2.1 Cold Deep In-Place Recycling Technique Problems

1. Soft spots of old road surface should be corrected before cold deep in-place recycling.
2. High load compactor took the materials was broken which affect to CBR of materials reduced, in this case is going true only the unbound granular materials which friction and interlocking, the materials, it is assign the CBR. In cement recycled base case, the broken of materials affect to CBR very small which activity in slab or rigid plate, but it should be as the activity in individual particle that same unbound granular base case hence the construction of cement/asphalt recycled base, the broken of materials while compaction is not important of cement recycled base compaction and should be used the high compactor machine to compact cement recycled base.
3. After constructing Cement/asphalt recycled base leaves dust. The contractor should clean dust after construction if dust and materials are in abundance, a grader should be used to clean materials. Dust also affects a prime coat on the base, permeating prime and final coats, reducing quality.

3.3 Material Properties in Engineering

Properties of materials in engineering included the reclaimed asphalt pavement and virgin aggregates for foamed asphalt mixtures and Portland cement mixtures.

3.3.1 Foamed Asphalt Mixtures Aggregates Properties

The material properties for foamed asphalt mixtures consist two things, reclaimed asphalt pavement and virgin aggregates. Most of reclaimed asphalt pavement was course aggregates, and the virgin aggregates had three size, 3/4, 3/8 inch and crushed stone. The reclaimed asphalt pavement and virgin aggregates properties required tests in the table 3.1 and 3.2.

Table 3.1 RAP aggregates properties for foamed asphalt mixtures

Properties	Method	Required
Moisture content	AASHTO T93	-
Atterberg Limits		
Liquid Limit	AASHTO T89	Max 25%
Plastic Index	AASHTO T90	4 - 8 %
Gradation	AASHTO T88	-
Compaction	AASHTO T180	-

Table 3.2 Virgin aggregates property for foamed asphalt mixtures

Properties	Method	Required
Gradation	AASHTO T88	-
Specific Gravity and Absorption	AASHTO T85	-

3.3.2 Asphalt Cement Properties

Tests the qualification of materials or asphalt cement (AC), it is following by the specification of asphalt cement or not, the tests perform to AASHTO, ASTM method determined, the asphalt cement separate two parts they are before and after oven dry tests, show in the Table 3.3 and 3.4.

Table 3.3 Original asphalt cement properties

Properties	Method	Required
Penetration (at 25˚C, 100g, 5 sec, 1/10 min)	AASHTO T49	60 - 70
Flash Point, Cleveland open cup (˚C)	AASHTO T48	Min 232
Ductility (at 25˚C 50 mm per min)	AASHTO T51	Min 100
Solubility (%)	AASHTO T44	Min 99
Softening Point (˚C)	AASHTO T53	49-54

Table 3.4 Oven-aged asphalt cement properties

Properties	Method	Required
Loss on heating (5 hours at 163˚C) %	AASHTO T74	Max 0.8
Penetration after heating (% of original)	AASHTO T49	Min 54
Ductility after heating (at 25˚C, 50mm per min) (cm)	AASHTO T51	Min 50

3.3.3 Aggregates Properties for Portland Cement Mixtures

The materials for Portland cement mix include reclaimed asphalt pavement aggregates 100%RAP per cement content. In this study the RAP aggregates determined by AASHTO and tests required are shown in Table 3.5.

Table 3.5 RAP aggregates properties for Portland cement mixtures

Properties	Method	Required
Moisture content	AASHTO T93	-
Atterberg Limits		
Liquid Limit	AASHTO T89	Max 25%
Plastic Index	AASHTO T90	4 - 8 %
Gradation	AASHTO T88	-
Compaction	AASHTO T180	-

3.4. Mix Designs

Two mix designs included foamed asphalt mix design and Portland cement mix design. Details of each mix design follow.

3.4.1 Foamed Asphalt Mix Design

3.4.1.1 Foamed Asphalt Characteristics

Foamed bitumen normally had two parameters in the tests. They were expansion ratio (ER) and Half-life, ER is the ratio of maximum volume of foamed bitumen relative to the original volume of bitumen after injecting water to hot bitumen. HL is the time taken for foamed bitumen to collapse from its maximum volume to half of the maximum volume in seconds.

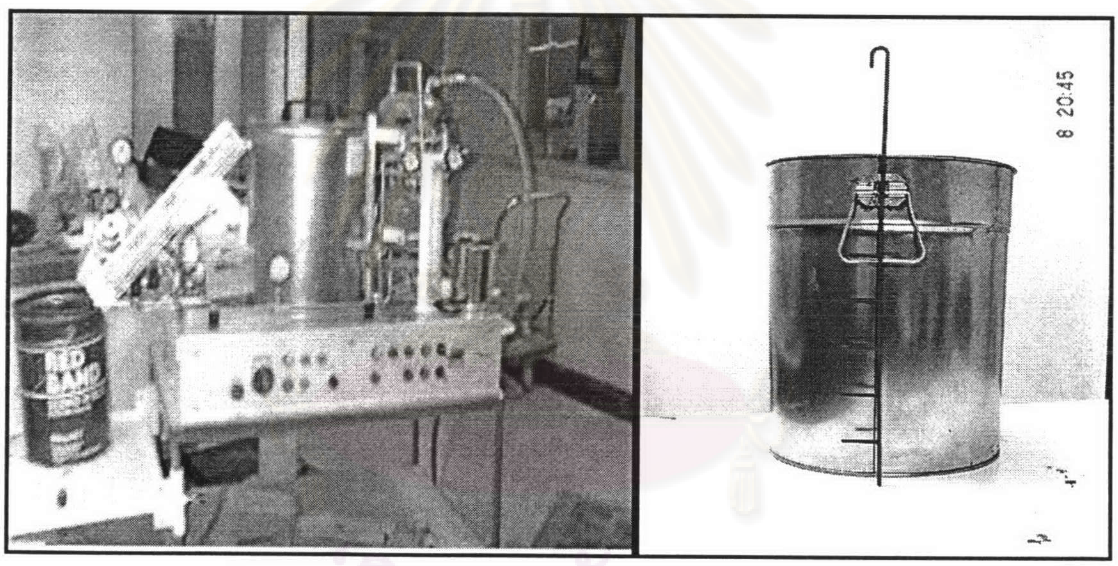

Figure 3.1 Foamed Bitumen Plant WLB 10 & Foaming Bucket

Source: Wirtgen Cold Recycling Manual

The foamed bitumen tests or foamed asphalt procedure is conducted by injecting water into hot bitumen, then testing the changing percentage of water within a rang temperature of 160-180°C to find the optimal expansion ratio and half-life. The water 1-5% at each temperature. The expansion ratio and halt life are a measure of temperature and water by Dip-Ruler. The tanker diameter is 28 cm, and its design for foamed bitumen procedure machine as shown in the Figure 3.1

The Dip-Ruler is put into the foamed bitumen tanker to measure foamed bitumen. Each mark is equal to 6 times expansion ratio. Temperatures and half-life are then recorded analysis.

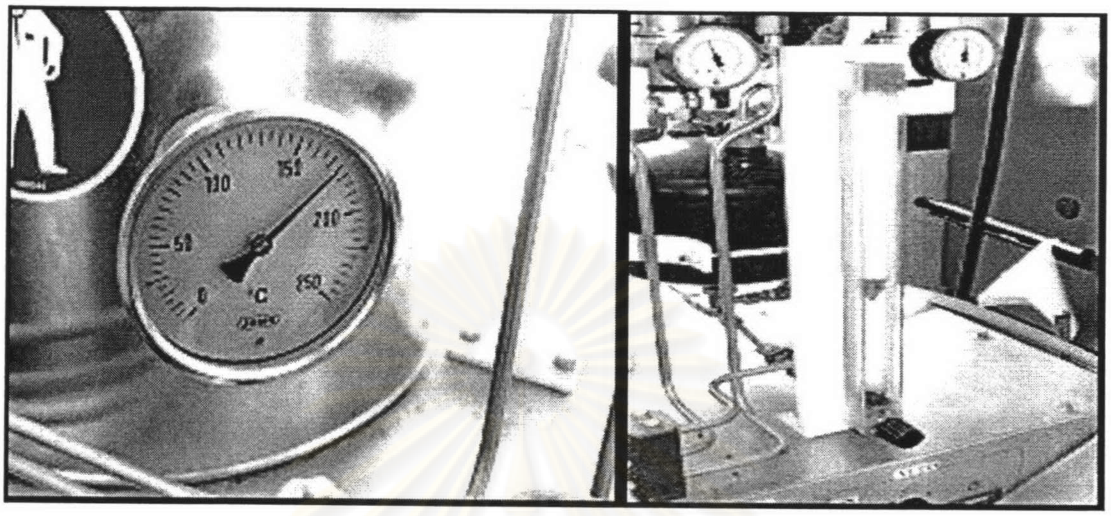

Figure 3.2 Thermometer & water flow-meters
(Bitumen Tank Temperature) (Adjust Values for Air and Water)

Source: Wirtgen Cold Recycling Manual

3.4.1.2 Aggregates Preparation

In this study, RAP and virgin aggregates were mixed together in three proportions:

100%RAP: Virgin Aggregates 0% by weight

50%RAP: Virgin Aggregates 50% by weight

0%RAP: Virgin Aggregates 100% by weight.

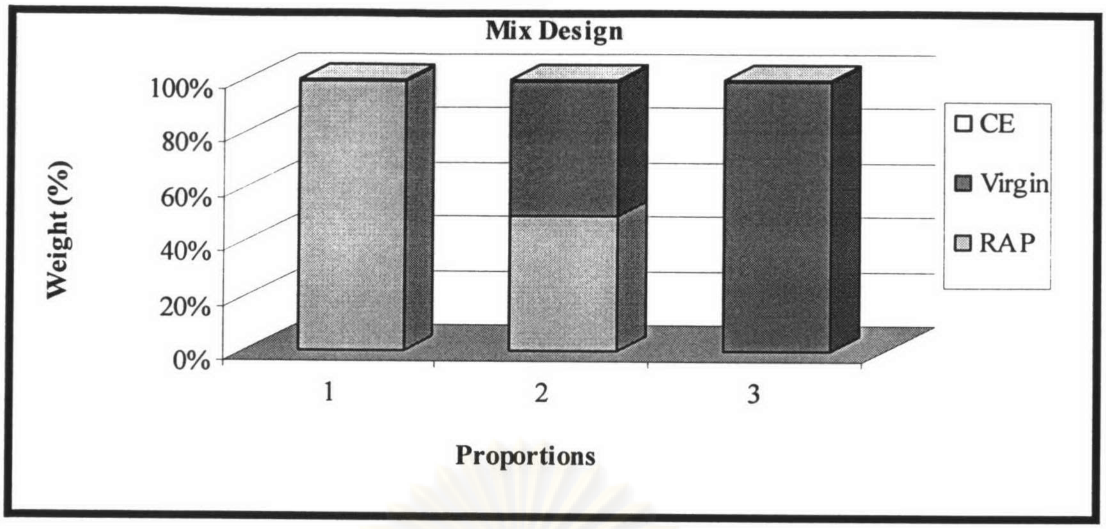

Figure 3.3 Proportion of foamed bitumen mix design

The RAP aggregate is proper for grade and milling materials on a road surface with 60 cm depth. The recycling machines have been developed over the years from modified milling machines and soil as shown in Figure: 3.4. The RAP aggregates from Phisanulok-Uttradid section 1. The RAP aggregates consist of 25% asphaltic concrete and 75% old base course.

The RAP and virgin aggregates were mixed together in three proportions 100% RAP, 50% RAP and 0% RAP, respectively. All the proportions of mix design had 1% cement. The new mix designs with optimum foamed bitumen were then tested.

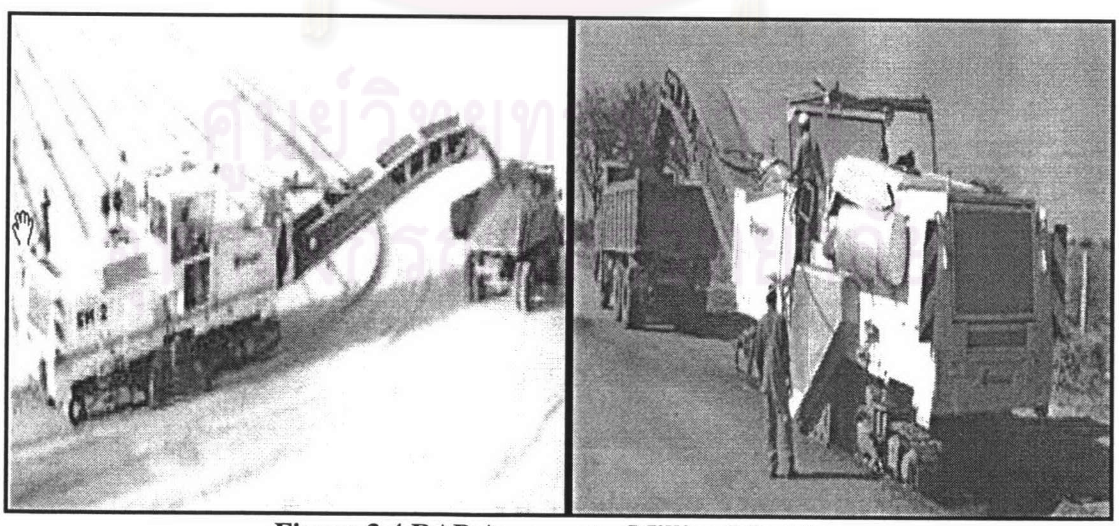

Figure 3.4 RAP Aggregates Milling Machine

Source: Bowering and Matin 1976

3.4.1.3 Aggregates Gradation

After RAP and virgin aggregates are mixed together, the three proportions are suitable for grading the range of specifications, shown in Figure: 3.5. From recommendation of literature review and the Wirtgen cold recycling manual for the materials suitability, the percentage passing the No 200 (0.075 mm) sieve were between 5-20% by weight because the filler and foamed bitumen mix together are like mortar binding the courser particles. Hence, the suitability of fine aggregates is very important for the foamed bitumen materials suitability as shown in Figure 3.5.

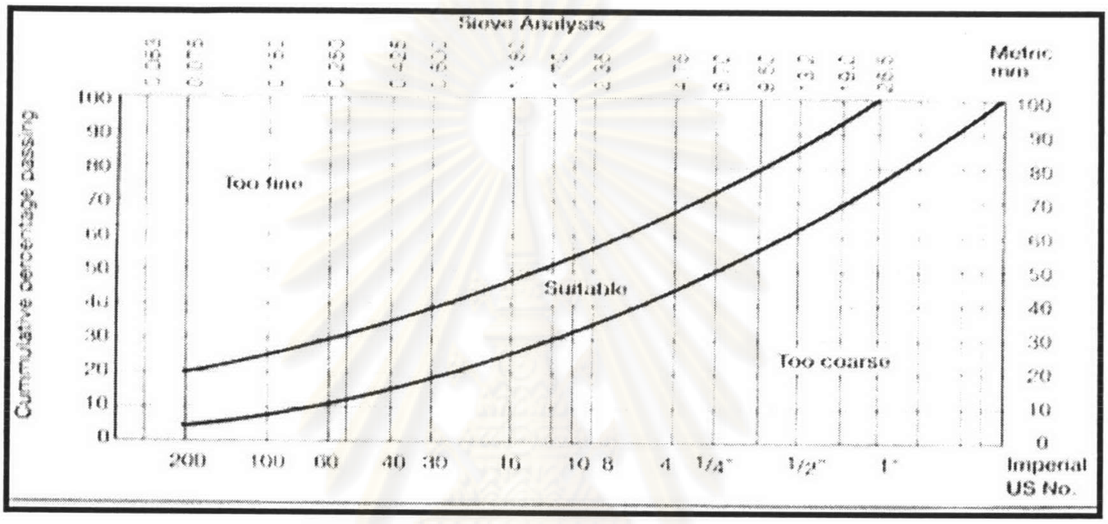

Figure 3.5 Range of RAP Aggregates

Source: Wirtgen Cold Recycling Manual 2001

The percentage passing No 200 (0.075 mm) sieve had to be less than 5% with no more than 2% of cement or limestone to each proportion because the flexibility of the aggregates mixture is reduced and affects fatigue resistance.

3.4.1.4 Compaction

The optimum moisture content duration of compacted foamed asphalt mixtures is very important as it can help the foamed asphalt distribution with aggregates and increase compacted density duration. When the RAP and virgin aggregates are combines the optimum moisture content (OMC) will be found by AASHTO T180.

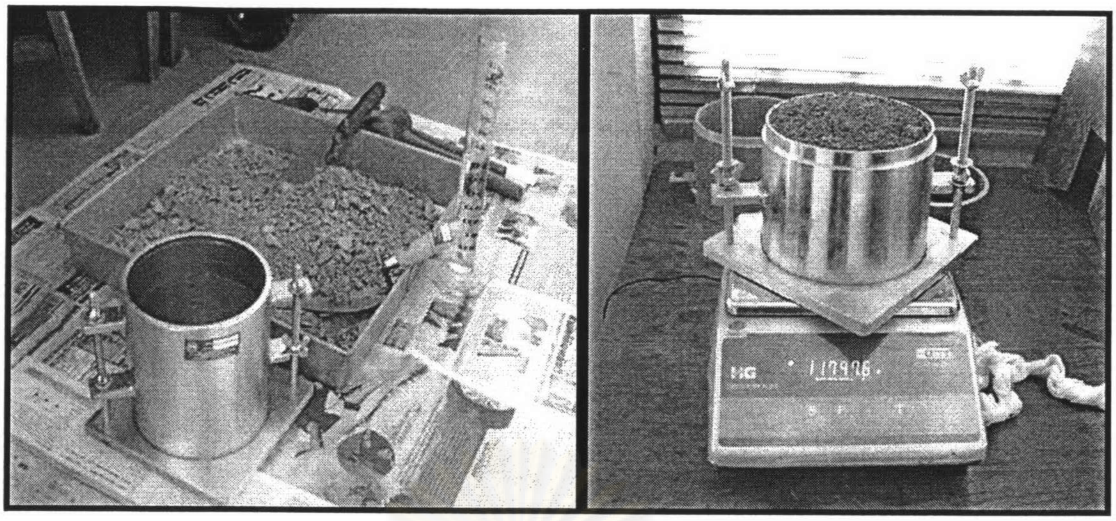

Figure 3.6 The Optimum Moisture Content

3.4.1.5 Foamed Asphalt Mixtures

When gave the foamed asphalt three proportions of aggregates are mixed, the optimum foamed asphalt content of each mixture for the cold recycling method will be found by following the Wirtgen Cold Recycling Manual 2001. The tests technique follows:

1. Mix the reclaimed asphalt pavement and virgin aggregates together with the optimum moisture content.
2. When the aggregates has optimum moisture content, the foamed asphalt is sprayed into the aggregates in the mixer from the foamed asphalt machine as shown in Figure 3.8. Then the mixture is compacted by Gyratory Compactor.
3. The sample compacted is cured at 40°C for 72 Hours.
4. The sample is separated into two groups to determine indirect tensile strength (ITS) in soaked and unsoaked conditions. For the soaked ITS, the sample was cured at 25°C for 24 hours.
5. The maximum dry density, soaked and unsoaked ITS and soaked and unsoaked ITS ratio (Retained ITS) of different foamed asphalt content value is then analyzed to find the optimum foamed asphalt content for the soaked ITS condition.

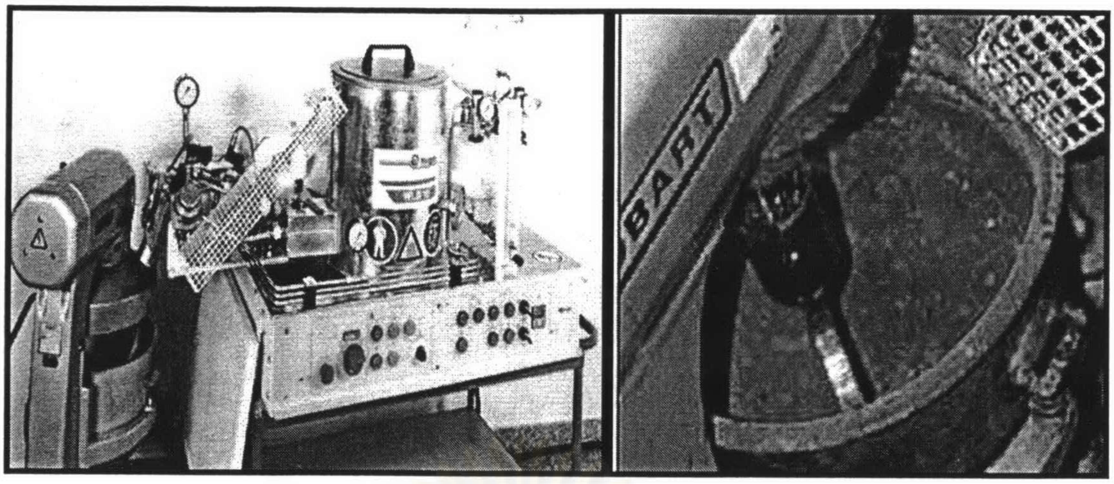

Figure 3.7 Foamed Bitumen Plant WLB 10 and Mixtures

Source: Wirtgen Cold Recycling Manual

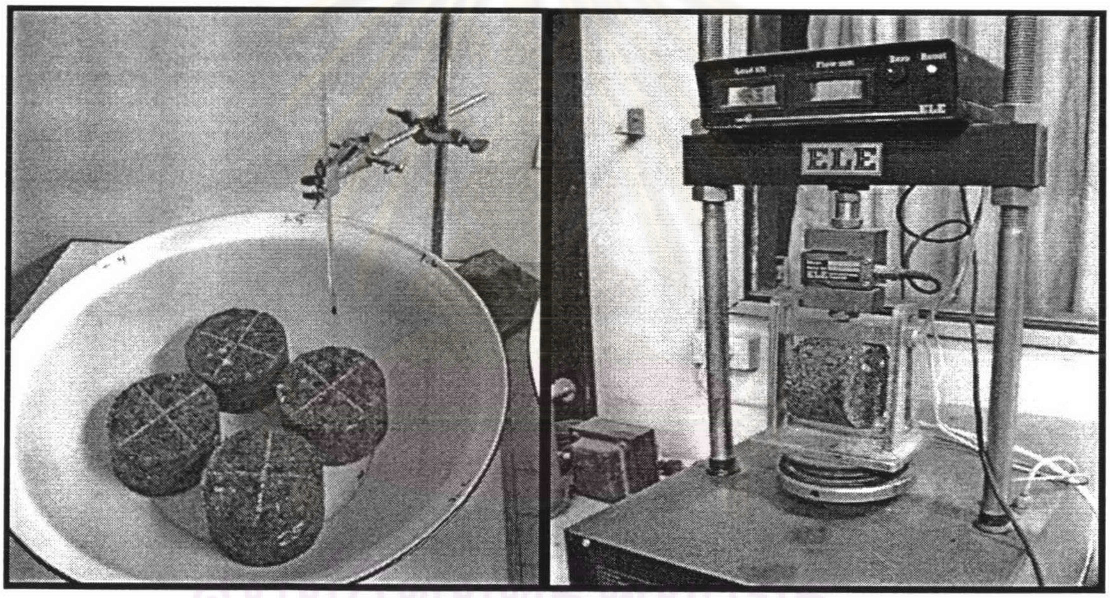

Figure 3.8 Soaked ITS Tests with ELE Marshall Tests 25

3.4.2 Portland Cement Mix Design

The reclaimed asphalt pavement aggregates are suitable for grade and milling materials on a road surface with 60 cm depth. The recycling machines have been developed over the years from modified milling machines and soil stabilizers. The RAP aggregates taken from the Phisanulok-Uttradid section 1 consists of 25% asphaltic concrete and 75% old base course.

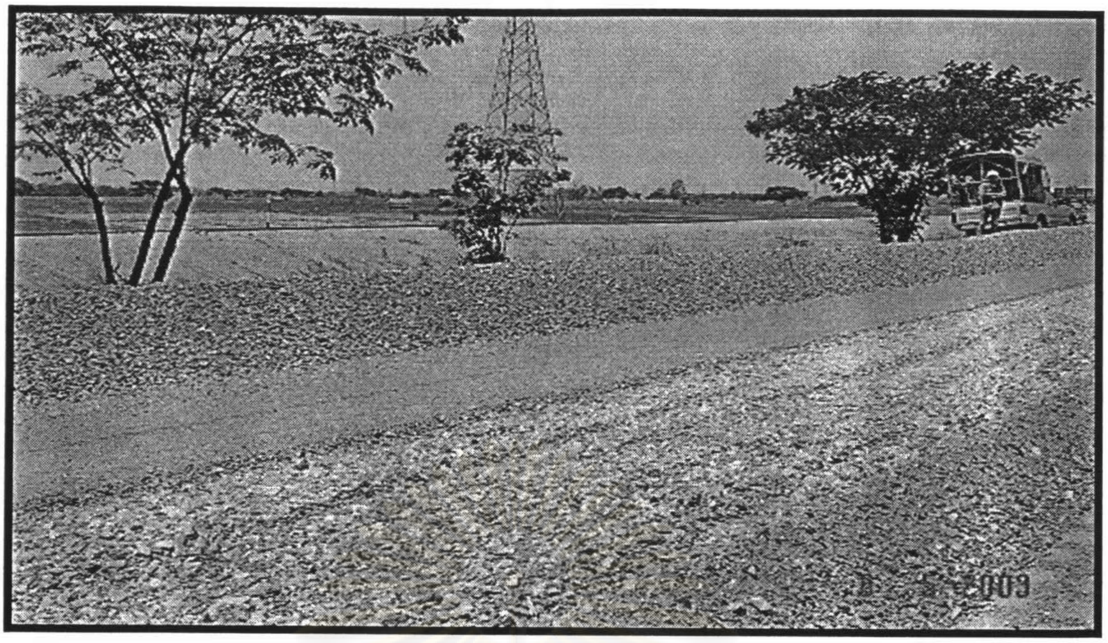

Figure 3.9 RAP Aggregates

Source: Phisanoulok Uttradit Section1

3.4.2.1 Aggregates Gradation

Portland cement mixtures gradation was performed by the AASHTO standard test method T88, following grading requirements, as shown in Table 3.6.

Table 3.6 Grading Requirements of Portland Cement Mix Design

AASHTO Sieve Sized		% Passing by weight
mm	inch	
50	2 ″	100
37.50	11/2 ″	70-100
25.00	1 ″	40-80
12.50	1/2 ″	30-60
4.75	No. 4	20-45
2.00	No. 10	10-35
0.425	No. 40	5-25
0.075	No. 100	5-15

3.4.2.2 Compaction

The Portland cement mixtures compaction performed by AASHTO T180 found the optimum moisture content of each mixture capable of increasing mixture density.

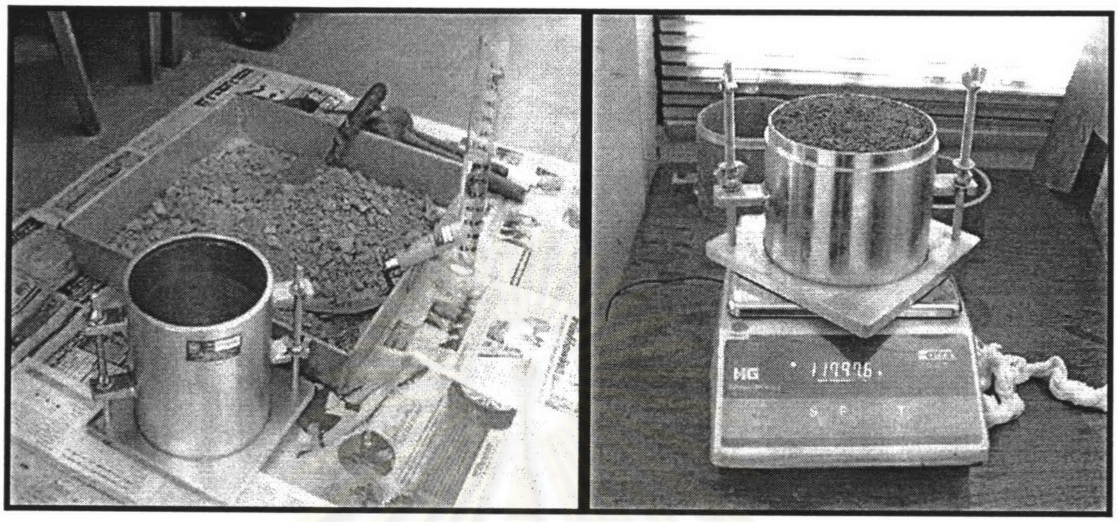

Figure 3.10 The Optimum Moisture Content

3.4.2.3 Portland Cement Mix Design

The Portland cement mixtures included RAP aggregates per cement contents, of 100%RAP per cement content of 2%, 3%, 4% and 5%, respectively, as shown Figure 3.11.

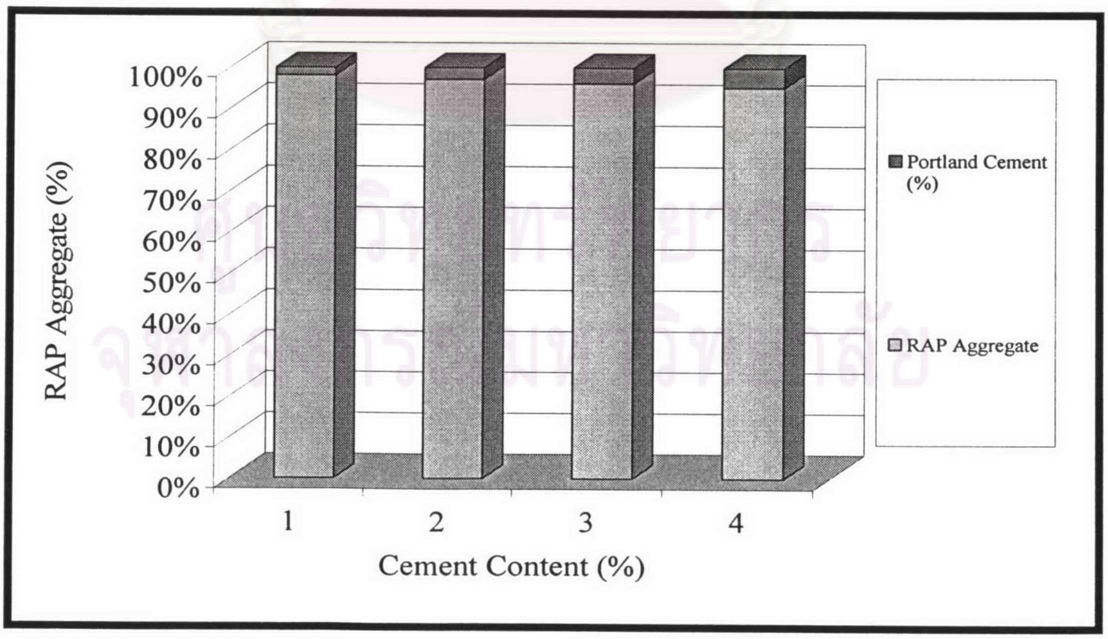

Figure 3.11 Proportion of Portland Cement Mix Design

3.5 Testing

Testing was conducted two samples of foamed asphalt mix and Portland cement mix designs.

3.5.1 Foamed Asphalt Mixtures Tests

The foamed asphalt mix design tests included indirect tensile strength, resilient modulus, fatigue resistance and permanent deformation.

3.5.1.1 Indirection Tensile Strength Tests

The ITS tests computes the ITS values according to load levels for a constant resilient modulus and constant deformation equal to 0.8333 mm per second, or 2 in/min at 25 °C and has on AASHTO T283 Resistance of compacted bituminous mixtures to moisture induced damage. Indirect tensile strength was calculated using Equation 3.1.

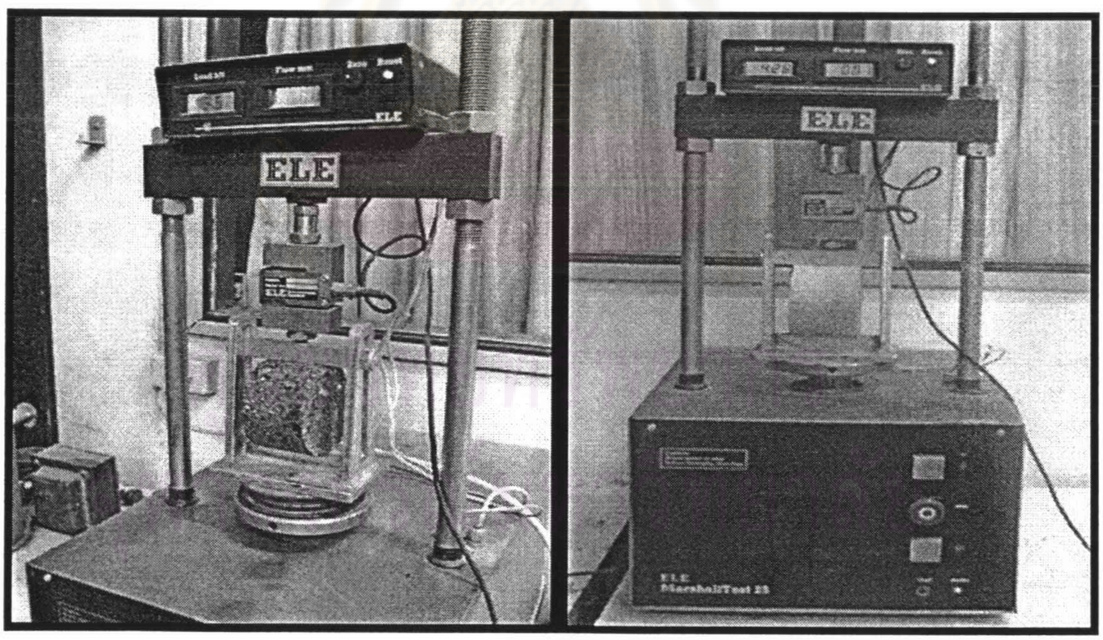

Figure 3.12 ITS of Foamed Asphalt Mixtures Tests with ELE Marshall Tests 25

$$ITS = \frac{(2 * P)}{(\pi * D * H)} \quad (3.1)$$

Where :

$ITS : Idirect \quad tensile \quad strength \quad (kPa)$

$P : Maximum \ aplied \ load \quad (kN)$

$D : Specimen \ diameter \quad (m)$

$H : Average \ height \ of \ specimen \quad (m)$

The ITS tests was separated into two types, soaked and unsoaked ITS to compute the Retained ITS relationship between the soaked and unsoaked ITS for a specific bitumen content.

$$\text{Re}tained \quad ITS = \frac{(2 * P)}{(\pi * D * H)}$$

Density :

$$D = \frac{(100)}{(W_{moist} + 100)} \times \frac{4 \times M_{Brig}}{(\Pi \times d^2 \times H)} \times 1000$$

$D : drydensity \quad (kg/m^3)$

W_{moist} : moisture content of specimen (% by mass)

M_{Brig} : mass of briquette immedaitely after compaction (g)

H : average height of briquette (cm)

d : diameter of briqquette (cm)

Note. $\frac{(100)}{(W_{moist} + 100)}$ *is the factor used to convert the wet density to dry density*

3.5.1.2 Resilient Modulus (M_R) Tests

Resilient Modulus (M_R) tests conducted by AASHTO TP31-94 standard tests method is used to determine the resilient modulus of the bituminous mixtures by indirection tension, while the ASTM D4123 standard tests determines indirect tension for resilient modulus of bitumen.

Resilient modulus was determined at four temperatures, with applied loads, from lower to higher temperatures as shown in Table 3.7

200 repetitions of the corresponding cyclic stress were conducted using Haversine-shaped load pulse consisting of 0.1 second repeat load with a 0.9 second relaxed load. Average recovered deformations for each LVDT were recorded separately for the last five cycles.

Table 3.7 Resilient Modulus Tests with Temperature of Foamed Asphalt Mixtures

Temperature (°C)	Force (%ITS)
15	25
25	20
35	15
45	10

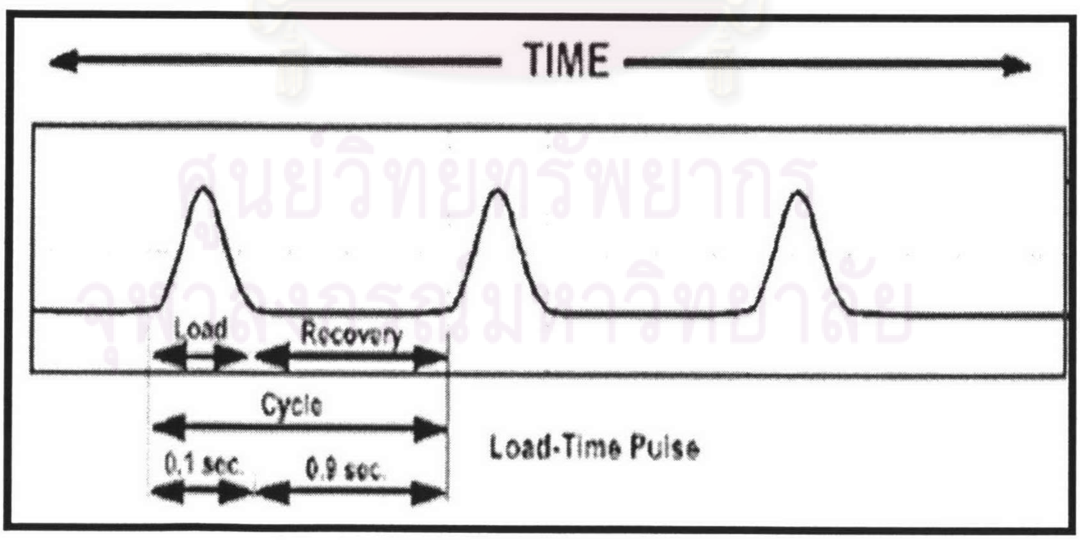

Figure 3.13 Repeated and relaxed load relationship

Source: Mc Lean, Virginia 22101-2296. August 1996

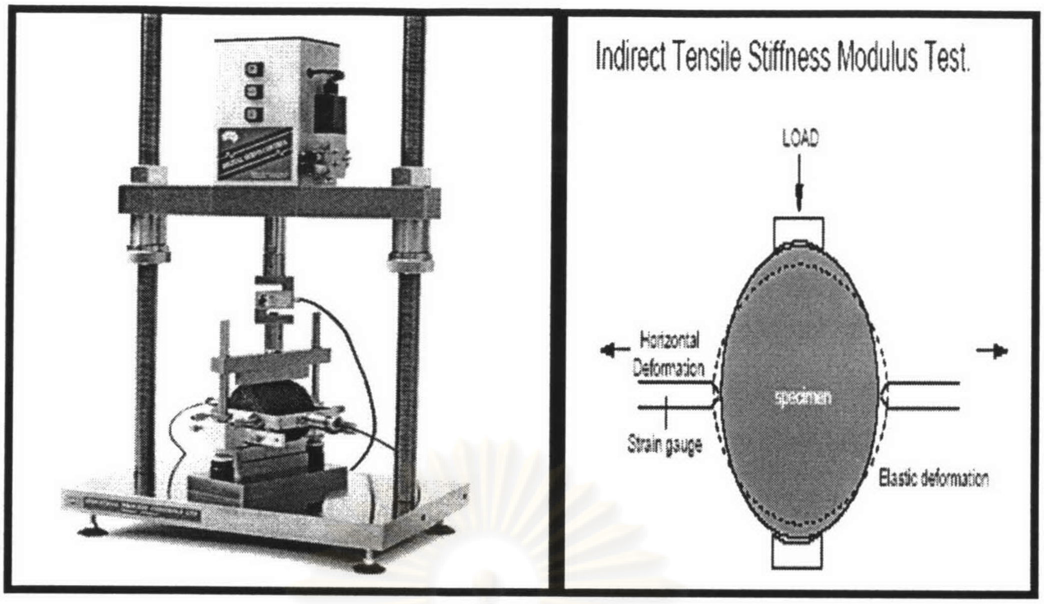

Figure 3.14 Resilient Modulus Tests with UTM-5P

Source: INOPAVE GROUP PTE LTD

3.5.1.3 Fatigue Resistance Tests

The Fatigue Resistance tests is similar to the resilient modulus tests with repeated load under constant stress until the resilient modulus values were reduced to 50% of the initial resilient modulus value. The tests was conducted at of 25°C with stress between 0.25 to 0.65 MPa, or 40% of indirect tensile strength.

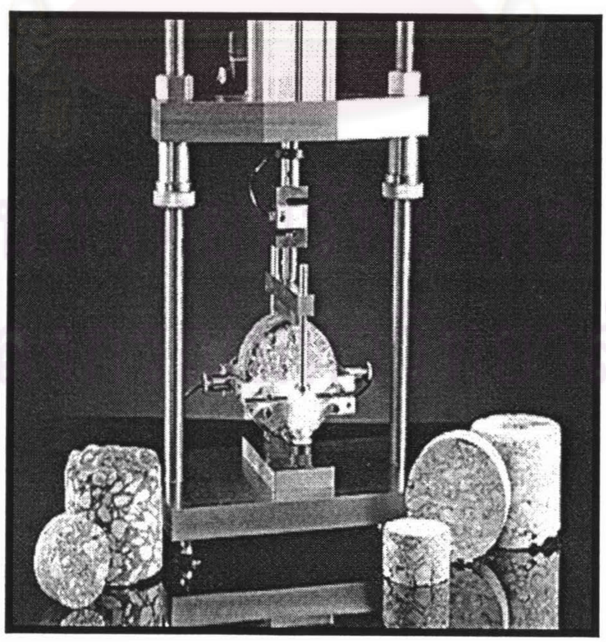

Figure 3.15 Fatigue tests with UTM-5P

Source: INOPAVE GROUP PTE LTD

3.5.1.4 Permanent Deformation Tests

Permanent deformation occurs in wheel paths due to repeated applications on the sample. Thus, repeated load deformation tests are useful to compare rutting susceptibility of different mixtures. Repeated load deformation tests by Dynamic Creep test. The repeated load deformation tests also utilize the UTM-5P, following the Australian standard tests method, AS 2891.12.1-1995. The tests applies axial compressive load to a specimen at a stress of 200 kPa until failure. The load applied is a rectangular shaped wave for a period of 0.5 seconds repeated with 1.5 seconds of rest at a frequency of 0.5 hertz. In this study, the load pulses were required to reach 40,000 cycles. The accumulated deformation was measured and strain calculated using Equation 3.2.

$$\varepsilon_P = \frac{\Delta_H}{H} \qquad (3.2)$$

Where:

ε_P : *Accumulated strain,* (mm/mm)

Δ_H : *Total axial deformation,* (mm)

H : *Original height of sample,* (mm)

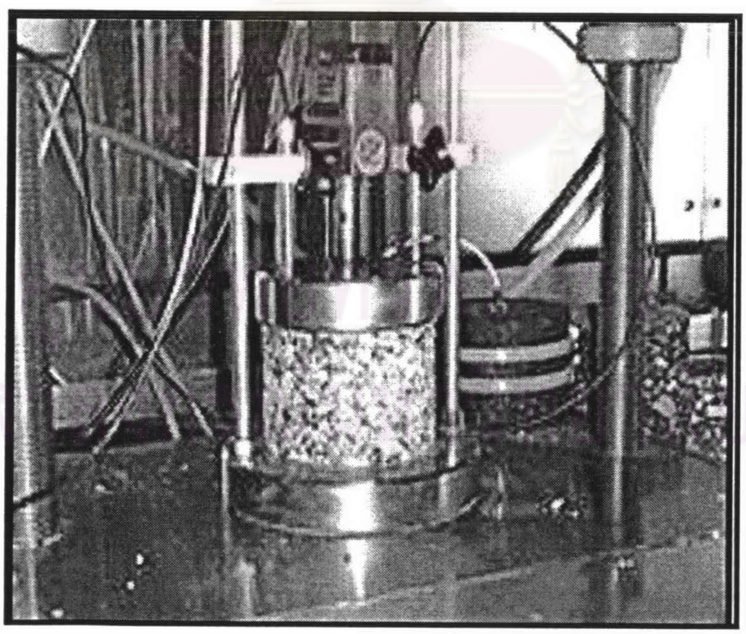

Figure 3.16 Permanent deformation tests with UTM-5P

Source: Bureau of road research & development of highways

3.5.2 Portland Cement Mixtures Tests

The Portland cement mixtures tests included the indirect tensile strength, resilient modulus and unconfined compressive strength.

3.5.2.1 Indirect Tensile Strength Tests

ITS tests computes ITS values according to the load level for resilient modulus which a constant load for constant deformation equal to 0.8333 mm per second, or 2 inch per minute at 25 °C and based on AASHTO T23 Resistance of compacted bituminous mixtures to moisture induced damage. The indirect tensile strength was calculated using Equation 3.3.

Figure 3.17 ITS Of Portland Cement Mixtures Tests with ELE Marshall Tests 25

$$ITS = \frac{(2 * P)}{(\pi * D * H)} \quad (3.3)$$

Where :

ITS : Idirect tensile strength (kPa)
P : Maximum aplied load (kN)
D : Specimen diameter (m)
H : Average height of specimen (m)

3.5.2.2 Resilient Modulus (M_R) Tests

Resilient Modulus (M_R) tests conducted by AASHTO TP31-94 standard tests method is used to determine the resilient modulus of the bituminous mixtures by indirect tension, while the ASTM D4123 standard tests method determines indirect tension for resilient modulus of bitumen.

200 repetitions of the corresponding cyclic stress were conducted using Haversine-shaped load pulse consisting of 0.1 second repeat load with a 0.9 second relaxed load. Average recovered deformations for each LVDT were recorded separately for the last five cycles.

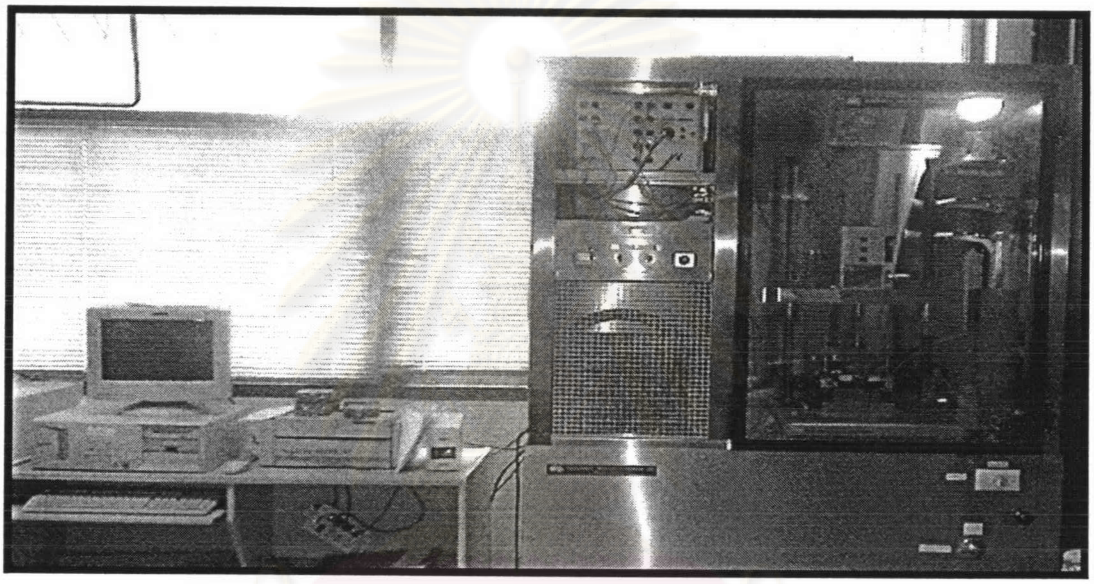

Figure 3.18 UTM-5P Used in This Study

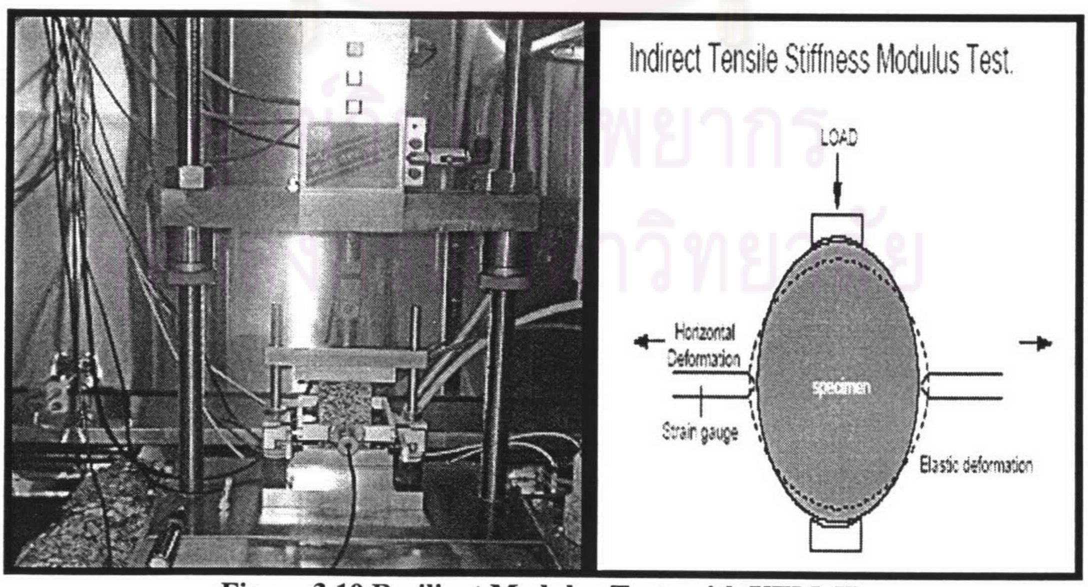

Figure 3.19 Resilient Modulus Tests with UTM-5P

Source: Bureau of Road Research & Development of Highways

3.5.2.3 Unconfined Compressive Strength Testing

Unconfined compressive strength (UCS) tests are conducted after removing specimens from curing. A cement content with UCS value of between 1.5 to 3.0 MPa is normally the target for recycling materials in the upper portion of a pavement. Calculation are made using Equation 3.4.

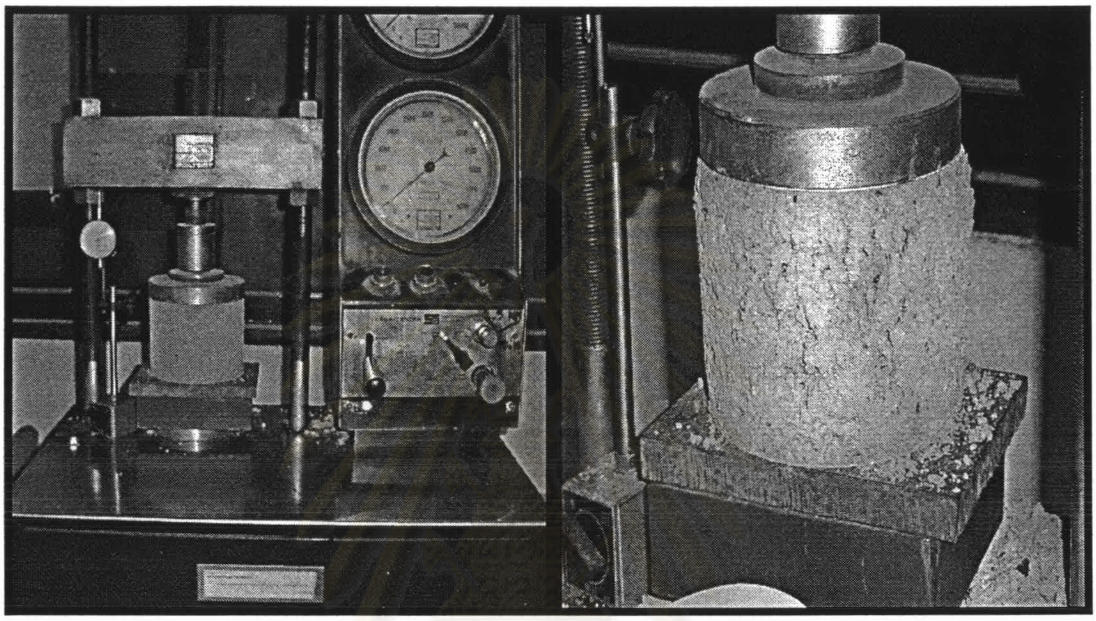

Figure 3.20 UCS Tests with Soil Tests, VERSATESTER 30 M

$$U = \frac{P}{(\pi \times r^2)} \qquad (3.4)$$

Where :

U : *Unconfined compressive strength* (*lb*)

P : *Load required to cruch specimens* (*lb*)

D : *Radius of specimens face* (*in*)