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COMPACTION AND CBR PROPERTIES OF RECLAIMED ASPHALT PAVEMENT MIXED WITH SAND

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Compaction and CBR properties of Reclaimed Asphalt Pavement mixed with Sand

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Supervisor

Assist. Prof. Dr. Volkan KALPAKCI

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Name of the student: Rahar Hama Fariq Faeq FAEQ

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Approval of the Graduate School of Natural and Applied Sciences.

Prof. Dr. M[illegible]ZCU
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Şafak TERCAN
Head of Department

This is to certify that we have read this thesis and that in our majority opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Volkan KALPAKCI
Supervisor

Name Examining Committee Members	Signature
Assist. Prof. Dr. Volkan KALPAKCI	....
Prof. Dr. Hanifi CANAKCI	....
Assist. Prof. Dr. Dlawar NASSANI	....

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Rabar FAEQ

ABSTRACT

COMPACTION AND CBR PROPERTIES OF RECLAIMED ASPHALT PAVEMENT MIXED WITH SAND

FAEQ, Rabar Hama Fariq Faeq
M.Sc. in Civil Engineering
Supervisor: Assist. Prof. Dr. Volkan KALPAKCI
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The use of recycled materials for construction is beneficial to both the environment and the economy. Reclaimed asphalt pavement (RAP) is one of the most commonly used recycled materials. RAP is most commonly used as an aggregate substitute in asphalt mix. It is also used as granular sub-base or base aggregate and embankment or fills material. The objective of this study was to evaluate the effect of the addition of sand to (RAP), on the compaction and strength of it. To achieve this objective of the study, five large pieces of asphalt cubes were collected from three different places (Maxmwr, Shaqlawa, Mosul street) in Erbil City/Iraq and experiments were conducted to find out their densities, water absorption, compressive strength and particle size distributions, RAP sample were mixed with 5%, %10, 15%, 20%, 25%, 50% by weight of poorly graded sand. Modified compaction, Soaked and Un-soaked CBR tests were performed on each mix, The modified proctor test were performed according to ASTM D 1557 for different sand/RAP mixtures, the results showed that increasing sand content in RAP caused an increase in maximum dry density (MDD) and optimum moisture content (OMC) of mixtures. Soaked and Un-soaked California bearing ratio test (CBR) was conducted at OMC for each mix. The results revealed that the increase in sand content for RAP samples resulted in an increase of CBR values for soaked and unsoaked samples. The RAP samples derived from different sources had different densities, water absorption and compressive strength values. None of the tested samples met the CBR requirements of the AASHTO Standards to be used as base or subbase.

Key Words: Reclaimed asphalt pavement, sand, compaction, CBR

ÖZET

KUM İLE KARIŞTIRILMIŞ ATIK ASFALTIN SIKIŞMA VE CBR ÖZELLİKLERİ

FAEQ, Rabar Hama Fariq Faeq
Yüksek Lisans, Inşaat Mühendisliği Bölümü
Tez Yöneticisi: Yrd. Doç. Dr. Volkan KALPAKCI
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Atık malzemelerin inşaat sektöründe kullanılması hem ekonomik hem de çevrenin korunması açısından oldukça faydalıdır. Atık asfalt (AA), geri dönüşümde kullanılan malzemelerden en önemlilerinden bir tanesi olarak ortaya çıkmaktadır. AA asfalt karışımında agrega yerine kullanılan en önemli malzeme haline gelmiş durumdadır. Ayrıca, yol yapımında temel, alt temel ve dolgu malzemesi olarak ta kullanılmaktadır. Bu çalışmada, atık asfalt malzemesi belirli oranlarda kumla karıştırılarak karışımın sıkışma ve mukavemet parametreleri üzerine etkisi incelenmiştir. Bu amaçla Irak'ın Erbil şehrinde beş farklı bölgeden (Maxmwr, Shaqlawa, Mosul) numuneler alınmış ve bu numuneler üzerinde yoğunluk, su emme, elek analizi ve CBR deneyleri yapılmıştır. Deneyler sonucunda bu beş farklı bölgeden elde edilen atık asfaltların farklı yoğunluk, su emme ve basınç mukavemetlerine sahip olduğu tespit edilmiştir. Öğütülerek agrega boyutlarına getirilen AA %5, %10, 1%5, %,20 %25 ve %50 oranlarında kumla karıştırıldıktan sonra, her bir karışım üzerinde modifiye Proktor ile kuru ve suya doygun CBR testleri yapılmıştır. Deney sonuçları, AA içine katılan kum miktarının artmasıyla maksimum kuru birim hacim ağırlığın ve optimum su muhtevasının arttığını ortaya koymuştur. Ayrıca, kum oranın artmasıyla CBR değerlerinin arttığı gözlenmiştir. Deney sonuçları, yapılan karışımlardan hiçbirinin AASHTO standartlarında temel ve alt temel yapımı için önerilen CBR şartlarını sağlamadığını ortaya koymuştur.

Anahtar Kelimeler: Atık asfalt, kum, sıkışma, CBR.

To My Parents, they should receive my greatest appreciation for their enormous love. They always respect what I want to do also give me their full support encouragement over the years.

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TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS/ ABBREVIATION

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
DOTs	Department of Transportation
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
RAP	Reclaimed Asphalt Pavement

CHAPTER 1

INTRODUCTION

1.1 General

Recycling is the reuse of material which has already served its first-intended purpose. Material removed from the surface of pavements as part of a maintenance program offers a source of cheap bitumen and aggregate since it is usually dumped or sold as fill material.

The need to reuse of recycled existing pavement materials for the reconstruction and rehabilitation of asphalt and Portland cement concrete pavements is of increasing importance. Recycling can help both to optimize the use of available materials and energy supplies. and to decrease the cost of maintenance for our highways, roads, and streets.

In the U.S.A. the Federal Highway Administration (FHWA) estimates the pavement industry generated 105.5$ million savings using recycled materials since 1985. And FHWA reports that 34 states have accepted some form of asphalt recycling in their specifications (Smith, 1979). Other major benefits of recycling are conservation of aggregates, binders, and energy, as well as preservation of the environment and existing highway geometry.

Recycling is not a new process. As early as 1915, asphalt paving surfaces had been recycled. However, the quantity of pavement materials recycled from 1915 to 1975 is small compared to the amount of recycling that has been taken place and is expected to occur between 1975 and 1990 as discussed in researched of Smith (1979).

In the past ten years there has been increasing emphasis on the need to reduce pavement rehabilitation costs and to conserve energy. Because of these facts, many authorities have reexamined and recognized the importance of recycling techniques.

Recycling can reduce not only cost and energy savings, but also the demand for asphalt during supply interruption (Smith, 1979).

1.2 Problem Statement

The interest in production of demolition and construction waste has been gradually increasing in past few years. The use of these materials as recycled unbound base course in new highway construction industry has become very common in the last twenty years. Usually, recycled roadway materials are generated and reused at the same construction site location, providing increased savings in money, time and energy.

Large amount of construction waste is produced each year and it is becoming more difficult to find appropriate sites for landfill. Recycled materials offer handy solutions to the concern, which is beneficial for both economy and environment. FHWA estimates that 100.1 million tons of Hot Mixed Asphalt (HMA) to be scraped and removed each year (Cosentino and Kalajian, 2001). Recycled Asphalt Pavement (RAP) is considered to be one of the most commonly used recycled materials. RAP is the term given to removed and/or reclaimed pavement materials containing asphalt and aggregates. RAP is generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. RAP consists of high-quality; well-graded aggregates covered and adhered by asphalt cement (RMRC, 2008).

The percent of RAP that can be recycled directly as a component of new hot-mix asphalt pavement is generally limited by approximately 25% of the new material; As a result the quantity of unused RAP continuously increasing, creating opportunities for using RAP in other applications and purposes.

Bennert and Maher (2005) investigated the blending RAP with virgin aggregates effects on the mechanical properties of these blends for use as base course and sub-base pavement materials. It has been found that the increase of RAP percent in the blends decreases the CBR of the RAP-virgin aggregate blends, therefore, it became necessary to find new ways to decrease the amount of space to store the millions of tons of RAP each year. Laboratory investigation on the different properties of RAP and its uses is also needed.

This work present the work results of a laboratory evaluation of strength and compaction characteristics of RAP-Sand blends to make a recommendation about its potential use as road base and subbase materials for highway construction.

1.3 Research Objectives

The main objective of this study is to present the results of a laboratory evaluation of RAP and sand blends. To achieve this objective, a number of tasks were proposed and completed:

1. Characterize the variability of RAP materials collected in terms of gradation.

2. Evaluate RAP- sand blends in terms of moisture-density characteristics and California bearing ratio (CBR), the mixes containing 100%, 95% ,90%, 85%,80%,75% and 50% RAP were considered.

3. Make recommendations about its potential use as road base and subbase materials for highway construction.

1.4 Thesis Layout

This thesis consists of five chapters. The introduction of the research topic, problem of statement and objectives are presented in first chapter. Findings based on literature review on past studies of related topics as well as recently published paper are introduced in second chapter. Description of materials, laboratory testing, detailed experimental procedure and standard followed by each test are introduced in chapter Three. Testing results and discussion are presented in chapter four. The conclusions and recommendations are presented in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Over the years, the escalation of the costs of manufacturing asphalt pavement increased the demand for recycling. Since the 1970s, the Federal Highway Administration (FHWA) has been promoting effective reuse of RAP materials (Copeland, 2011).

The main aim behind the recycling efforts are to reduce construction waste, conservation of non-renewable natural resources, as well as lower energy costs. Usually, balanced economic savings and environmental benefits of using recycled materials are dependent on the performance requirements of the pavement design. It is generally recognized that the use of recycled construction materials to the maximum extent possible should be carried out in the overall context of maintenance of cost-effective, high-quality, well-performing, and environmentally sound pavement infrastructure.

Collins and Ciesielski (1994), in an NCHRP Synthesis of Highway Practice, noted that highway agencies have been proactive in the recycling of reclaimed and by product materials into construction materials, with RAP being the material most frequently used. In addition to its use in asphalt mixtures, they identified unbound base and subbase as “proven” applications for RAP, with grading identified as the limiting factor for use. Although 49 states in (USA) indicated they used RAP, the primary use was in asphalt concrete. Thirteen states, indicated RAP use in base materials; four states used RAP in subbase material, and RAP was used in stabilized base and shoulder aggregate, each in two states. Overall, the performance of granular base and subbase layers containing RAP material has been characterized as satisfactory to excellent (Collins and Ciesielski, 1994).

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In a recent study, Saeed (2007) indicated that 16 state DOTs allowed the use of 100% RAP as aggregate in unbound pavement layers and 5 DOTs restricted the use of RAP to 50% or less by weight.

2.2 Recycled Asphalt pavement

Reclaimed or recycled asphalt pavement (RAP) is the term given to removed or reprocessed pavement materials containing asphalt and aggregates. These materials are obtained when asphalt pavements are removed for reconstruction, resurfacing, or to gain access to buried utilities. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement (FHWA, 1998).

2.3 Obtaining RAP

Asphalt pavement is removed, typically by milling or removing full-depth. Milling involves the removing pavement surface using a milling machine, which can remove up to 2 in thickness in a single pass. Full-depth removal involves ripping and breaking the pavement using a rhino horn on a bulldozer or pneumatic pavement breakers. In most cases, the broken material is picked up by front-end loaders and loaded into haul trucks. The material is then hauled to a central facility for processing. At this facility, the RAP is processed using a series of operations, including crushing, screening, conveying, and stacking (FHWA, 1998).

Although the majorities of old asphalt pavements recycling in central processing plants, asphalt pavements may also be pulverized in place and incorporated into granular or stabilized base courses using a self-propelled pulverizing machine. Hot in-place and cold in-place recycling processes have evolved into continuous train operations which include partial depth removal of the pavement surface, mixing the reclaimed material with beneficiating additives (such as virgin aggregate, binder, and/or softening or rejuvenating agents to improve binder properties), and placing and compacting the resultant mix in a single pass (FHWA, 1998).

2.4 Benefits of asphalt recycling:

- Reuse and non-renewable natural resources preservation.
- Conservation of the environment and land filling reduction.
- Energy preservation.
- Shorter construction periods.
- Increased level of traffic safety within construction work zone.
- Conservation of existing roadway geometry and clearances.
- Corrections to pavement profile and cross-slope.
- Improved smoothness of pavement.
- Improving physical properties of pavement by modifying of existing aggregate gradation, and asphalt binder properties.
- Elimination of reflective cracking with some methods.
- Improved performance of roadway.
- The cost reduction in comparison with traditional methods of rehabilitation (FHWA, 2001).

2.5 Use of Reclaimed Asphalt Pavement

According to FHWA, the majority of RAP is used in construction and maintenance applications, including:

- Hot in-place recycling
- Cold in-place recycling
- Full-depth reclamation
- Road base aggregate
- Shoulder surfacing and widening (FHWA, 1998)

2.5.1 Hot Mix Asphalt (In-Place Recycling)

The asphalt pavement softened through heating, and is scarified or hot milled and mixed to a depth of ¾ to 1½ inches (18.75-37.5 mm). New hot-mix material (virgin aggregate and new binder) or a recycling agent is added in a single pass of a specialized machine in the train. A new wearing course may also be added with an additional pass after compaction (Davio, 1999).

2.5.2 Cold Mix Asphalt (In-Place Recycling)

In cold in-place recycling, the pavement is removed by cold planning to a depth of 3 to 4 inches (75-100 mm). The material is then pulverized, sized, and mixed with an additive. Virgin aggregate may be added to modify RAP characteristics. An asphalt emulsion or a recycling agent is added. Once the gradation and asphalt content meet specifications, the material is placed and compacted. An additional layer is optional, such as a chip seal or 1 to 3 inches (75-100 mm) of hot-mix asphalt on top (Davio, 1999).

2.5.3 Full-Depth Reclamation

In process of reclamation of full-depth, all of the asphalt pavement section and a portion of the underlying materials are processed to obtain a stabilized base course. The materials are crushed and additives are introduced. The materials are then shaped and compacted with the addition of a surface or wearing course that is applied on top (Davio, 1999) to the actual recycling operation.

2.5.4 Granular Base Aggregate

For production of granular base or subbase aggregate, RAP must be crushed, screened, and mixed with conventional granular aggregate, or sometimes recycled concrete material. Mixing granular RAP with suitable materials is necessary to achieve the bearing strengths needed for most load-bearing unbound granular applications. RAP by itself may exhibit a somewhat lower bearing capacity than conventional granular aggregate bases.

2.5.5 Embankment or Fill

RAP material may also be used as a granular fill or base for embankment or backfill construction, although such an application is not widely used and does not represent the highest or most suitable use for the RAP. Using RAP as an embankment base may be a practical alternative for material that is stored for significant period of time, or may be mixed from several different sources of project. Use as an embankment base or fill material within the same right-of-way may also be a suitable alternative to the disposal of excess asphalt concrete that is generated on a particular highway project.

2.6 Properties of RAP and RAP Blends

The properties of RAP are governed by the milling and crushing operation, as well as by the characteristics of the binder and aggregate in the old asphalt pavement from which the RAP is obtained. RAP produced from surface courses (compared to binder courses) is usually of a higher quality because of higher quality aggregates used in the original construction (Saeed, 2008).

When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement. However, RAP derived from different sources can have significantly different engineering properties due to the differences in milling process, rock source, type and content of asphalt, etc. RAP combined from several sources may change the quality of the product throughout the construction project because of this variation. Some of the physical, mechanical and engineering properties of RAP and RAP blends are of particular interest when RAP is used in granular base or subbase applications. These properties include gradation, compacted density, moisture content, permeability, durability, bearing capacity and permanent deformation.

2.6.1 Gradation

The gradation for milled RAP is determined by the teeth spacing of the milling or pulverizing unit and the speed of pulverizing. Wider tooth spacing and higher speed result in larger particle sizes and coarser gradation. The gradation is also affected by the original HMA gradation and the temperature of the HMA during milling or pulverizing process. Results from sieve analysis of RAP are mixed, particularly for the fines content. Both low fines content and high fines content in stockpiled RAP have been observed. The particles passing the #200 sieve can be as high as more than 10% (Sullivan, 1996) and as low as less than 0.5 % (McGarrah, 2007). Typical RAP gradations after milling or processing from FHWA (Chesner et al., 1998), TxDOT (Rathje et al., 2002), NJDOT (Bennett et al., 2000) and FDOT (Cosentino and Kalajian, 2001) are shown in Figure 2.1. The variation in gradation for the RAP materials from different sources is evident (Yuan et al., 2010).

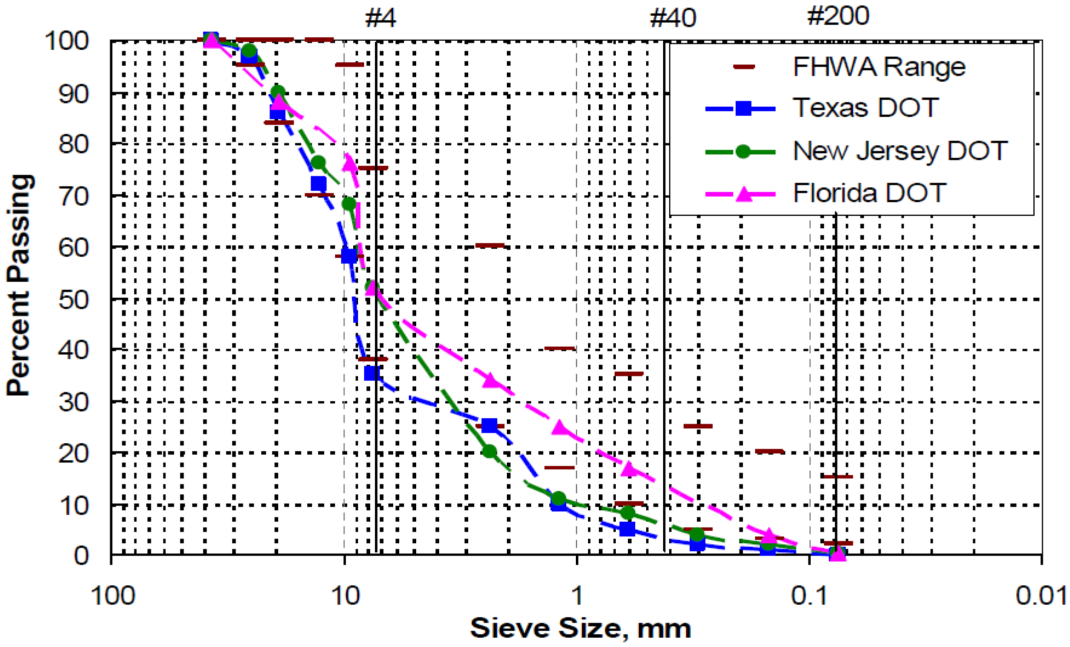

Figure 2.1 Typical gradations for RAP (Yuan et al., 2010)

The gradation of the milled or crushed RAP is different from that of the original HMA. Milling and scrapping can cause RAP aggregate degradation which is normally finer and denser than the virgin aggregates. The degradation during milling is a function of the aggregate top size and gradation of the aggregate in the asphalt pavement. During milling, the aggregate fraction passing #4 sieve increases from a pre-milled range of 41 to 69% to a post-milled range of 52 to 72 %. Similarly, the fraction passing the No. 200 sieve increases from 6 to 10% to about 8 to 12% (Kandhal and Mallick, 1997). However, full depth pulverizing or scrapping does not cause as much degradation as milling (Ahmad et al., 2004). Further degradation might occur for milled or crushed RAP due to compaction; in particular, for particle

Table 2.1 Gradation of RAP, Schaertl and Edil (2009)

Material	% Passing											
	#200	#100	#50	#30	#16	#8	#4	3/8"	1/2"	3/4"	1	1.5
Bejarano pulverized	2	3	7	12	20	31	46	68	…..	100	…..	…..
Guthrie R1	8	11	15	23	35	45	58	82	…..	99	…..	…..
Guthrie R2	1	3	8	12	21	39	59	82	…..	97	…..	…..
bennert RAP	1	2	3	5	10	20	39	68	…..	90	…..	…..
Saeed RAP-LS-MS	3	5	9	12	19	27	38	62	75	95	95	100
Saeed RAP-GR-CO	1	2	5	12	18	25	39	63	75	92	97	100
Saeed RAP-GV-LA	0	2	6	11	17	23	33	61	76	92	98	100
Average Value	2.3	4.0	7.6	12.4	20.0	30	44.6	69.4	75.3	95.0	96.7	100
Standard Deviation	2.7	3.3	3.8	5.3	7.5	9	10.2	9.0	0.6	3.8	1.5	0.0
Coefficient of variance	1.2	0.8	0.5	0.4	0.4	0.3	0.2	0.1	0.0	0.0	0.0	0.0

sizes greater than 0.5 in. (Maher et al., 1997). Degradation of the larger particles is attributed to the debonding of the aggregates held together by the asphalt binder.

In the study of Schaertl and Edil (2009), the available estimated gradations of the RAP were presented which are shown in Table 2.1.

2.6.2 Moisture – Density Relationship

The presence of asphalt reduces the amount of water required to achieve the necessary compaction level of the reclaimed asphalt pavement (RAP) mixture, because of the surface coating of stone particles (Stroup- Gardiner and Wattenberg-Komas, 2013). This factor must be taken into account when the suitable moisture content for compaction is determined. Locander (2009) noted that as the RAP fraction of the base layer increases, the required optimum moisture content (OMC) to achieve compaction decreases. Cooley determined OMC and maximum dry unit weight (MDUW) for samples containing different percentages of RAP using modified proctor compaction method. The results indicated that the increasing percentage of RAP caused a decrease of OMC and MDUW (Cooley, 2005).

Guthrie et al. (1999) also found that an increasing the content of RAP led to a decrease in the value of MDD and OMC .The particles of aggregate in the RAP were partially covered in asphalt, which decreased the specific gravity. It was further assumed that the partial asphalt coating reduced the aggregate water absorption potential and inter-particle friction, leading to a decrease the amount of water required to achieve MDD.

McGarrah (2007) surveyed U.S. states and summarized current RAP practices in the WSDOT report WA-RD 713.1. The literature findings on RAP and RAP blends are shown in Table 2.2 included data on density, moisture and CBR. In general the density, optimum moisture content and CBR decrease with the addition of RAP.

Table 2.2 Literature summary (McGarrah, 2007)

Report	Blended[1]	Dry Density[2]	Moisture Content[3]	CBR[4]
Sayed (1993)	No	….	Decreased	Decreased
Garg & Thompson (1996)	No	Decreased	Increased	Decreased
Papp (1998)	Yes	Decreased	Decreased	….
MacGregor (1999)	Yes	….	….	….
Taha (1999)	Yes	Decreased	No Change	Decreased
Cooley (2005)	Yes	Decreased	Decreased	Decreased
Bennert & Maher (2005)	Yes	Decreased	Decreased	….
Trzebiatowski (2005)	No	Decreased	….	….

1. Details whether the RAP was blended with virgin aggregate.

2. Effect on the dry density of the material as the percent RAP increased.

3. Effect on the optimum moisture content as the percent RAP increased.

4. Effect on the CBR as the percent RAP increased.

The literature findings developed by Cosentino et al. (2008) are shown in Table 2.3. RAP applications include base, subbase and subgrade work. Various processing methods have been used. Six of the 10 works cited used milled RAP. The top size was 1.5 inch with generally less than 2% passing the #200 sieve. The USCS classification was well graded sand or gravel (i.e., SW or GW) in nearly all cases. The AASHTO classification was A-1-a. Optimum moisture ranged between 5.4% and 8.5% which is typical for granular material. Low densities were obtained for 100 % RAP; blends and special compaction procedures produced higher values.

Table 2.3 Summary of RAP engineering properties (Cosetino et al., 2008)

Study	Author	Year	RAP Application	Process	Gradation		Soil Classification		Compaction		
					passing 1.5 in sieve	Passing #200 sieve	USCS	AASHTO	Optimum Moisture (%)	Mod proctor Max Dry density (ib/ft2)	Standard Proctor max Dry Density (ib/ft2)
100% RAP											
SR 500 Holopaw FL	Sayed et al.	1993	Shoulder and Base	Milled	97%	4%	GW/SW	A-1-a	6.20%	122.9	
Lincoln Avenue IL	Garg & Thampson	1996	Base course	Crushed	100%	4%	GW/Gp	A-1-a	7.20%	125.1	81
US Route 1 NJ	Maher et al.	1997	Base and Subbase		93%	0%	GW	A-1-a	5.50%		113
SH 395 CA	Bejarano et al.	2003	Puverized Base		98%	2%	GW	A-1-a	5.50%	145.6	
Florida Tech Research	Montemayor	1998	Base and Subbase		100%	0.50%	GW/SW	A-1-a	7/8.5%	112	104
Florida Tech Research	Gomez	2003	Base and Subbase	Crushed	98%	0%	GW	A-1-a	80%	117.8	
Florida Tech Research	Cleary	2005	Backfill	Crushed	100%	1%	GW/SW	A-1-a	7%	116.8	114.3
RAP-Soil Mixture											
Kuwait	Aljassar et al.	2005	Subgrade	Milled	100%	6.50%	GW	A-1-a	8.50%	127.5	
University of Montana	Mokwa and peebles	2005	Base & Subbase	Milled	96%	1%	GW	A-1-a	5.40%	131.3	
Oman	Taha et al.	1999	Base & Subbase	Milled	100	0.50%	GW	A-1-a	7.30%	117.3	

2.6.3 California Bearing Ratio

D' Andrea (2001) found that using RAP to the sub base layer and subgrade is a handy solution to get rid of a large quantity of waste generated during maintenance and rehabilitation. To avoid excessive deformation problems because of using RAP, it is necessary to mix it with another type of aggregate, like construction and demolition aggregate, to strengthen the mixture until reaching a suitable level of resistance to static and dynamic loads. In Taha et al. (1999) RAP and RAP/virgin aggregate blends used as both road base and subbase in the Sultanate of Oman were evaluated through a laboratory experiments. Gradation, compaction, and bearing strength tests were performed on RAP/aggregate blends of 0%, 20%, 40%, 60%, 80% and 100% RAP. The virgin aggregate was a mix of well graded sand and gravelly sand with little or no fines. RAP was obtained through milling and contained 5.5% asphalt content. The 100% RAP produced the lowest bearing strength, with a CBR of 11. Taha et al. (1999) recommended that blends with 60% or less RAP were suitable for road subbase construction. For base construction, however, only mixes containing 10% RAP or less were recommended.

Cooley (2005) tested subrounded and angular aggregate base materials, as well as RAP from two different locations. RAP contents of 0, 25, 50, 75, and 100% were utilized in a full-factorial experimental design with three replicates of each unique combination. It found that the main effect of RAP content indicate that CBR values decrease with increasing RAP contents. The addition of 25% RAP causes a 29% decrease in strength compared to the neat base material, and the strength declines 13 to 15% with each additional 25% increase in RAP content.

McGarrah (2007) examining published studies on the characteristics of RAP mixes used in unbound base applications and concluded that 100% RAP does not produce a product of adequate base course quality and should not be allowed. As the RAP content increased, the shear strength of the blend decreased below the required level. McGarrah recommended reducing the content of RAP to 25% and blending RAP with the virgin aggregate at the mixing plant. Dong and Huang (2014) recommended there is no 100% RAP unbound base used under asphalt pavements. Schaefer et al. (2008) concluded that 20% to 50% RAP content is usually used in actual construction.

Ooi (2010) concluded that limiting RAP to 50% may be prudent as long as the material meets all other requirements in the specifications that a virgin aggregate would satisfy. In addition, Ooi recommended minimum CBR values of 80 and 60 for base and subbase aggregate blends, respectively. The intent was to provide performance specifications expressed in terms of CBR test results.

Sultan et al. (2013) conducted laboratory evaluation to investigate and examine different RAP/virgin aggregate blending techniques to improve the mechanical characteristics of local RAP materials in Iraq. A detailed laboratory testing program was conducted to achieve the gradation, CBR, and other strength coefficients. It was found that the blending of up to 40% RAP materials with different local virgin sub-base materials improves the RAP mechanical characteristics to meet SCRB (2003) requirements for road sub-base materials and provides economical, environmental, and sustainable road construction technique in Iraq.

Taha et al. (2014) conducted a laboratory testing program to present the results on the use of combined excavation waste (EW) and RAP aggregates in the construction of road bases and sub-bases. Physical and chemical properties were determined. Different combinations of both materials were subjected to compaction and California Bearing Ratio (CBR) testing in accordance with Qatar Construction Specifications. The results indicated that materials failed to meet some of the Qatari standards such as Los Angeles abrasion, liquid limit, plasticity index and CBR specified for road construction.

Ansori and Radam (2015) conducted laboratory evaluations of RAP and RAP/virgin aggregate blends used as a foundation for pavement base in Indonesia. Abration, specific gravity, compaction, and bearing strength tests were performed on RAP/aggregate blends of 0%, 3%, 6%, 9%, 12%, RAP. RAP was obtained through milling and contained 3.98% asphalt content. 100% RAP produced the lowest bearing strength with a CBR of 16.6. Ansori and Radam (2015) recommended that the materials from reclaimed asphalt pavement layers can be used for the base courses by no more than 3 percent, for the sub-base courses by no more than 9 percent, and for the courses without asphalt coverings or shoulders by no more than 10 percent.

CHAPTER 3

RESEARCH PROGRAM AND TEST PROCEDURES

3.1 Introduction

This chapter presents the test program, the description and properties of both the native materials (in this case, the sand used) and the RAP, then the engineering properties of the sand-RAP mixtures with different percentages and proportions.

3.2 Research Program

The material selection and test procedure are the first aspects of any experimental research. The general classification and physical properties of the materials such as grain size distribution analysis by sieve tests determined prior to mix the different contents. In addition, the compaction characteristics of those materials (maximum dry density and optimum moisture content) have been investigated by performing Modified Proctor Test. Though the actual goal of the research is to examine the strength, therefore CBR are performed in various cases and conditions to make a comparison and choose the best materials proportions. The research program carried out to achieve the maximum strength and CBR value is presented in Figure 3.1.

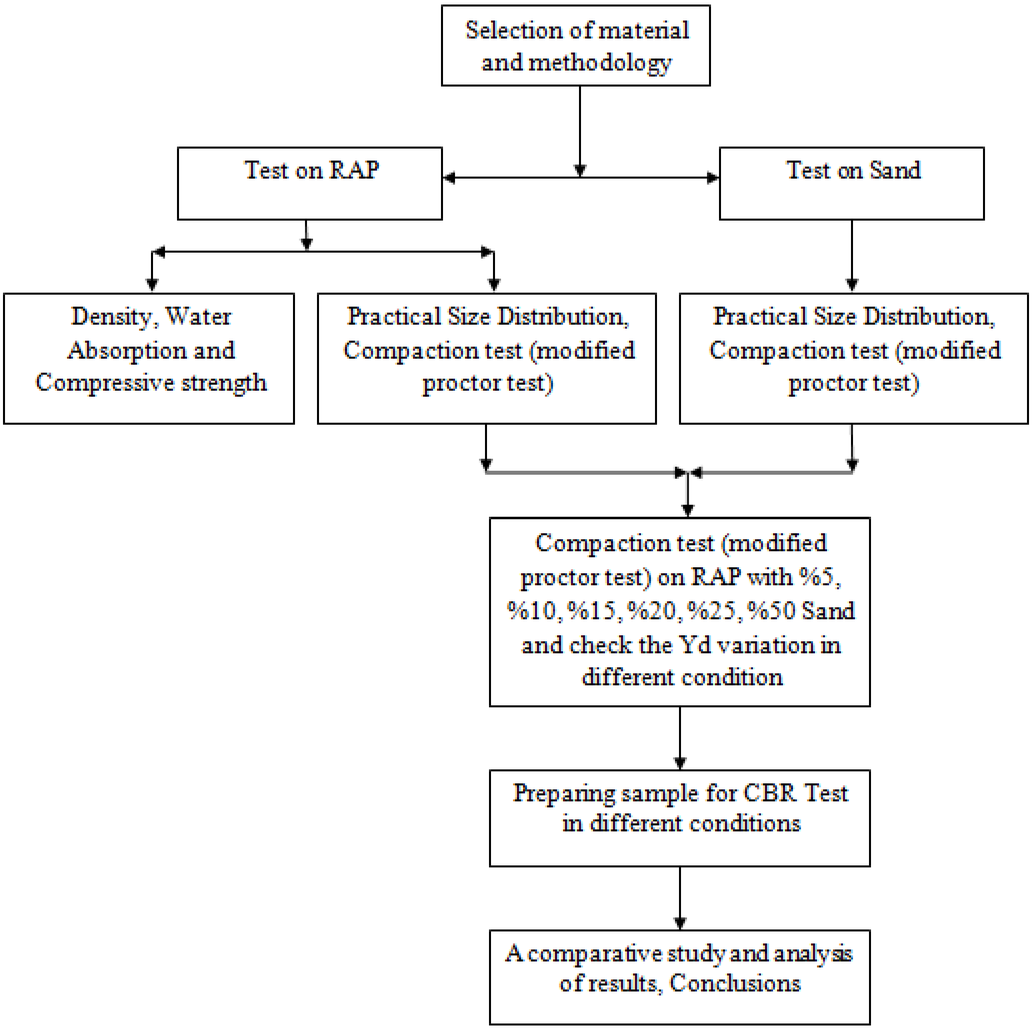

Figure 3.1 Research program

3.3 Materials

3.3.1 RAP

The RAP used in this research study was collected from three different locations (Shaqlawa, Maxmwr, Mosul street) in Erbil City/Iraq. Initially, the experiments have been conducted on two types of samples: undisturbed asphalt sample (in order to examine the materials properties in each place) and crushed specimens which passed through sieve of 19mm size. Properties of collected samples from the RAP material used in this study are summarized in table 3.1. Several tests had been conducted as following:

Table 3.1 Different properties of RAP

Property	Value		
Place	Maxmwr Street	Shaqlawa street	Mosul street
Density (g/cm$^{3)}$	2.17	2.21	2.25
Water absorption (%)	0.95	0.72	0.6
Compressive Strength (MPa)	8.04	8.97	9.9
Maximum dry density	2.04 g/cm^3		
Optimum moisture content	5.40%		
CBR	4.92%		

3.3.2 Sand

The sand used in the research work has been collected from khabat region in Erbil City/Iraq. The main properties of the sand are listed in the table below:

Table 3.2 Different Properties of Sand

Property	Value
Maximum dry density	1.97 g/cm^3
Optimum moisture content	9.80%
CBR	14.18%

3.4 EXPERIMENTAL INVESTIGATIONS

3.4.1 Compressive strength test

In the study of strength of materials, the compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting stress vs strain. In this study five asphalt cubes (5*5*5) cm from three different places has been taken, the test were conducted according to ASTM C39, A 50 kN capacity device was used, and the load was applied at constant rate of stress at 0.57 MPa/sec.

Figure 3.2 Compressive strength device

3.4.2 Water Absorption test

Water absorption test used for finding the amount of absorbed water under specified conditions, the tests were conducted according to ASTM D 570.

The procedure of the test can be summarized as follows, firstly the specimens are dried in an oven at (40) degree, for 24 hr and then placed in a desiccators to cool, immediately upon cooling the specimens are weighs (W1), then specimens are immersed in water for about 24 hrs, after specimens are removed, the surface of samples are cleaned with absorbent cloth, and weighed again as (W2).then the water absorption defined as given below in Eq. 3.1.

$$\text{Water Absorption (\%)} = ((W2 - W1)/W1) * 100 \quad (3.1)$$

3.4.3 Particle Size Distribution

The compositions of soil particles are different in sizes and shapes. The range of particle size in a same soil sample may from very several microns to several centimeters. Many physical properties of the soil such as its density, permeability strength, etc are dependent on size and shape of these particles in the soil sample. Sieve analysis is used for determine the particle size distribution in coarse –grained soils while sedimentation analysis is applied for same reason in fine grained soil. Both are followed by plotting the results on a semi-logarithm graph where ordinate is the percentage finer and the abscissa is the particle diameter i.e. sieve sizes on a logarithmic scale.

The results from sieve analysis of the soil when plotted on a semi-log graph with particle diameter or the sieve size in millimeter as the X-axis with logarithmic axis and the percentage finer as the Y-axis. This semi-log graph gives a clear idea about the particle size distribution. From the help of this curve, D10 and D60 are resolute. This D10 is the diameter of the soil below which 10% of the soil particles lie. The ratio of, D10 and D60 gives the uniformity coefficient (Cu) which in turn is a measure of the particle size range in the soil sample.

3.4.4 Compaction Test (Modified Proctor Test)

This test is necessary to indicate the relationship between the maximum dry unit weight of soil and the moisture content associated with it. The soil is compacted in a mold with standard dimensions with a 5.5Ib hammer dropped from a height of 12 inches. This test is a laboratory method to determine the optimum moisture content O.M.C for a given soil sample at which it's maximum dry density can be accomplished. The test name Proctor represents the name of its demonstrator R. R. Proctor who connected between the compaction density and the water content in 1933. His exceptional test is called Standard Proctor Compaction Test, which is recently advanced to be the modified Proctor compaction test.

The procedures of those two tests are almost the same except for few changes. The reason behind the modification is increasing the compaction load. The modified hammer weighs 10Ib and the height of the drop is 18 inches. The mold used has standard size and cylindrical in shape.

The soil is placed into the mold gradually by dividing it into equal layers; each one is compacted by number of drops using the hammer. This methodology is then repeated for distinctive qualities of humidity material and the dry unit weights are determined for each one case. In this case soil is filled in a number of five equal layers with 25 blows in each one layer. The hammer and the mold for modified proctor test are shown in Figure 3.2.

The graphical relationship of the dry density to moisture content is then plotted to establish the compaction curve. The determined curve comes in parabolic shape and dry density value is increasing up to maximum and after that again the value decreased. The maximum dry density is then obtained from the peak point of the compaction curve and its corresponding moisture content, which is known as the optimum moisture content (OMC). Used formulas are listed below in equations (3.2), (3.3) and (3.4).

Normal wet density=(Weight of wet soil in mould gms)/(Volume of mould cc) (3.2)

Moisture content (%) = (Weight of water gms)/(Weight of drysoil)*100 (3.3)

Dry density γd (gm/cc)=((Weight dwnsity))/(1+((Moisture content)/100)) (3.4)

Figure 3.3 Modified proctor test apparatus

3.4.5 California Bearing Ratio Test

CBR is the ratio of force for every unit region needed to enter a soil mass with standard load at the rate of 1.25 mm/min to that required to ensure penetration of a standard material. The standard loads utilized for diverse penetrations for the standard material with a CBR value of 100% are listed in Table 3-3.This standard load is taking limestone as a standard material and its CBR value at 2.5 mm, 5 mm, 7.5mm & 10 mm penetration are fixed as standard load for CBR value determination.

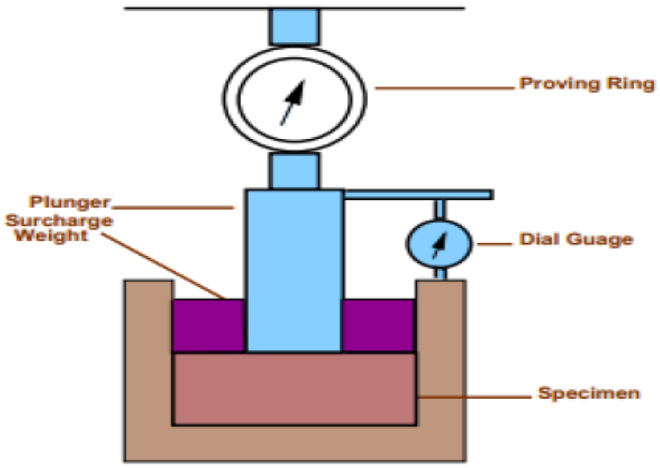

Figure 3.4 California bearing ratio testing machine

CBR value is calculated in Eq. 3.5:

C.B.R = (Test Load / Standard load) * 100 (3.5)

Standard load is for particular depth of penetration of plunger is given bellow.

Table 3.3 Standard load in different penetration

Penetration of plunger (mm)	Standard Load (Kg)
2.5	1370
5	2055
7.5	2630
10	3180

The CBR test was done on a compacted RAP material, the sample has been compacted dynamically into the 5.9inches diameter and 6.9inches height mold by 56 drops per layer on five layers by using the Modified Proctor hammer of 10Ib weight and 18 inches height. A piston with 50mm diameter has been used to penetrate the soil and three surcharge weights have been used to confine the soil inside the mold to simulate the pavement weights of on the soil. A 50mm displacer plate placed inside the mold. CBR qualities of both drenched and in un-soaked specimens are determined. Load is connected so that the penetration is roughly 1.25 mm/min rate. The load readings are recorded at distinctive penetrations, 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 8, 9, 10, 11, 12, and 12.5 mm.

The curve is generally convex upwards although the initial part of the curve may be concave upwards due to surface irregularities, if so, then a correction is applied by drawing a tangent to the curve at the point of greatest slope. The corrected origin will be the point where the tangent meets the x-axis. The CBR values are usually calculated for penetrations of 2.5 mm and 5mm. Mostly the CBR values at 2.5mm penetration will be larger than that for 5mm penetration and in such case the previous is taken as the CBR value for design purposes of an asphalt structure. If the CBR value for 5mm penetration is greater than that for 2.5mm penetration, then the test must repeated. On the off chance that indistinguishable results take after, the bearing ratio relating to 5mm penetration is taken for design.

CHAPTER 4

TEST RESULTS AND DISCUSSIONS

4.1 Compressive strength, Water absorption & Density

Five cubes had been taken from three different places, and the size of samples was 5*5*5 cm. The water absorption and compressive strength test were performed for each sample. The results indicated that samples from Mosul street had the highest density and compressive strength as compared to samples from other places, on the other hand, the sample from Maxmwr had the highest water absorption ratio. The average density, water absorption and compressive strength of samples, are given below in Table 4.1.

Table 4.1 Average density, average water absorption and average compressive strength

Sample place	Average Density (g/cm^3)	Average Water Absorption (%)	Average Compressive strength (MPa)
Maxmwr street	2.17	0.95	8.04
Shaqlawa street	2.21	0.72	8.97
Mosul street	2.25	0.6	9.9

4.2 Grain size distribution (sieve analysis)

The test was performed in accordance with ASTM D 422. Eleven sieves were used. And the results from sieve analysis of the soil were plotted on a semi-log graph with the sieve size in X axis and percentage finer in Y axis. The particle size distribution of RAP and sand are given in Table 4.2 and plotted in Figure 4.1.

Table 4.2 Sieve analysis result

Sieve Number	SAND	RAP
	Percent Passing	Percent Passing
3/4"	0	99.3
3/8"	0	57.6
No. 4	99.9	26.6
No. 10	73.3	6.1
No. 18	56.7	1.8
No. 30	46.5	1.3
No. 40	28.4	1.1
No. 50	15.7	1
No. 100	5	0.8
No. 120	3.3	0.7
No. 200	1.2	0.7

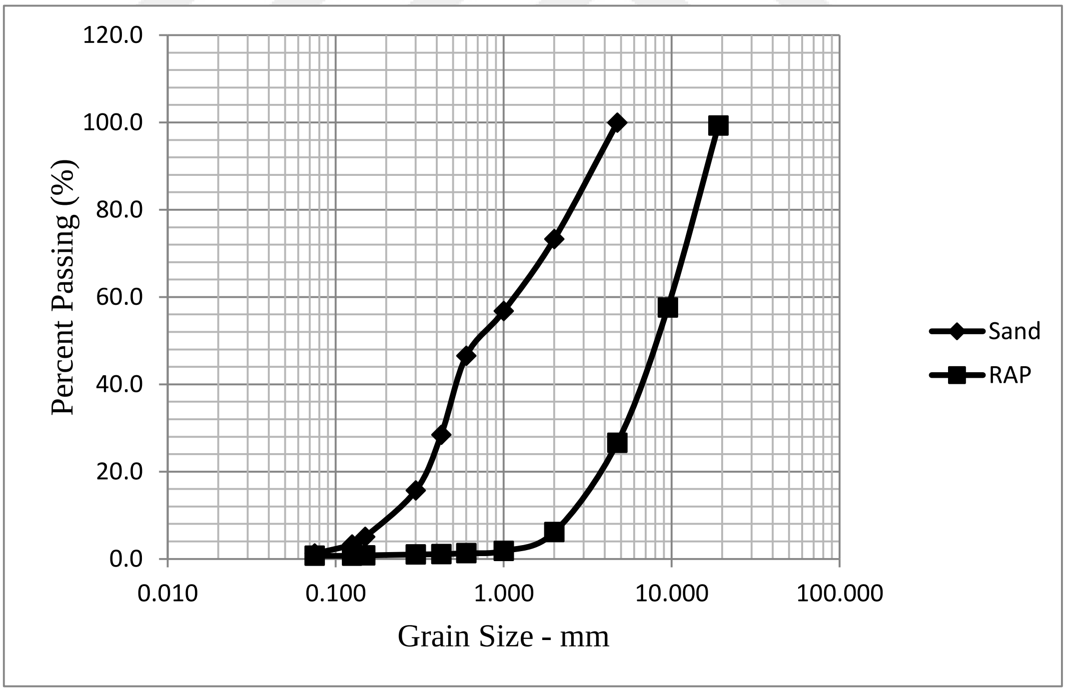

Figure 4.1 grain size distribution graph

The particle size distribution of RAP show a gradation with 99.9% coarse material (74% gravel; 25.9% sand) and 0.1% fines; a C_u = 3.7 and C_c = 1.2 and can be described as poorly graded gravel with sand. On the other hand, the particle size distribution for soil sample (sand) show a gradation with 99.9% coarse material (100% sand) and 0.1% fines; having C_u = 5.91 and C_c = 0.72 and can be described as poorly graded sand.

4.3 Compaction Test

4.3.1 Sand

Modified proctor test was executed for 6000 g soil sample for each trial. The test was conducted according to ASTM 1557 standards. From this test, maximum dry density of the sample was found to be 1.97 g/cm^3 and OMC was equal to 9.8%. Moisture content vs. dry density plotted for sand sample is given below in Figure 4.2.

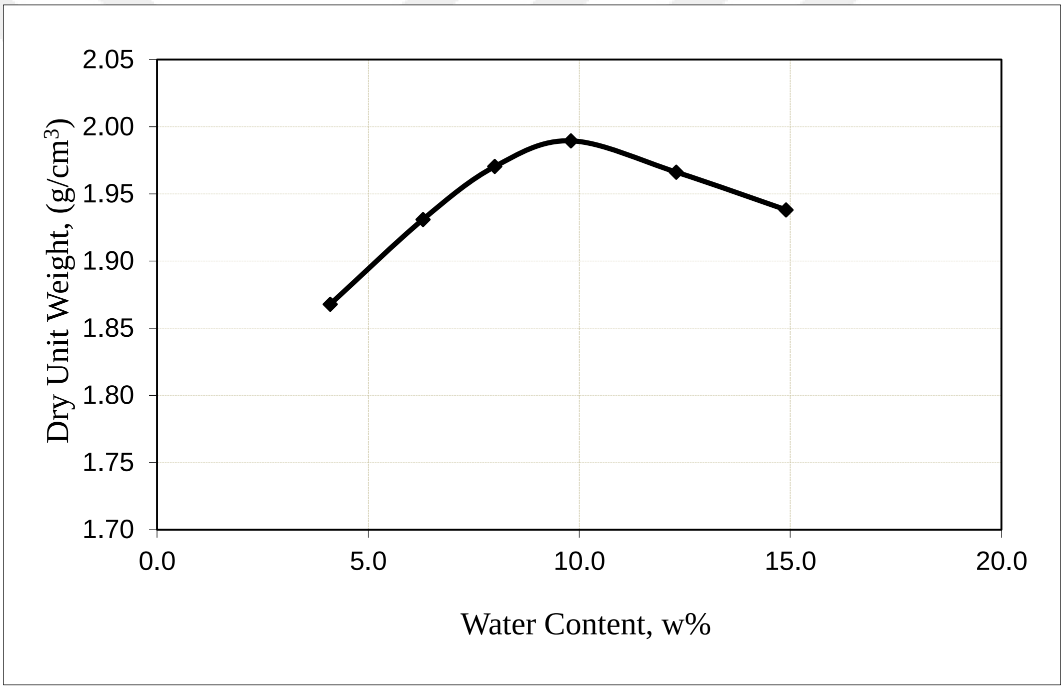

Figure 4.2 Modified Proctor Test result

4.3.2 Reclaimed Asphalt pavement

Modified proctor test were carried out according to ASTM 1557 standards. For the RAP, in order to establish the optimum moisture contents (OMC) corresponding to their respective maximum dry densities. Maximum dry density with optimum moisture content for (RAP) sample can be seen in Figure 4.3.

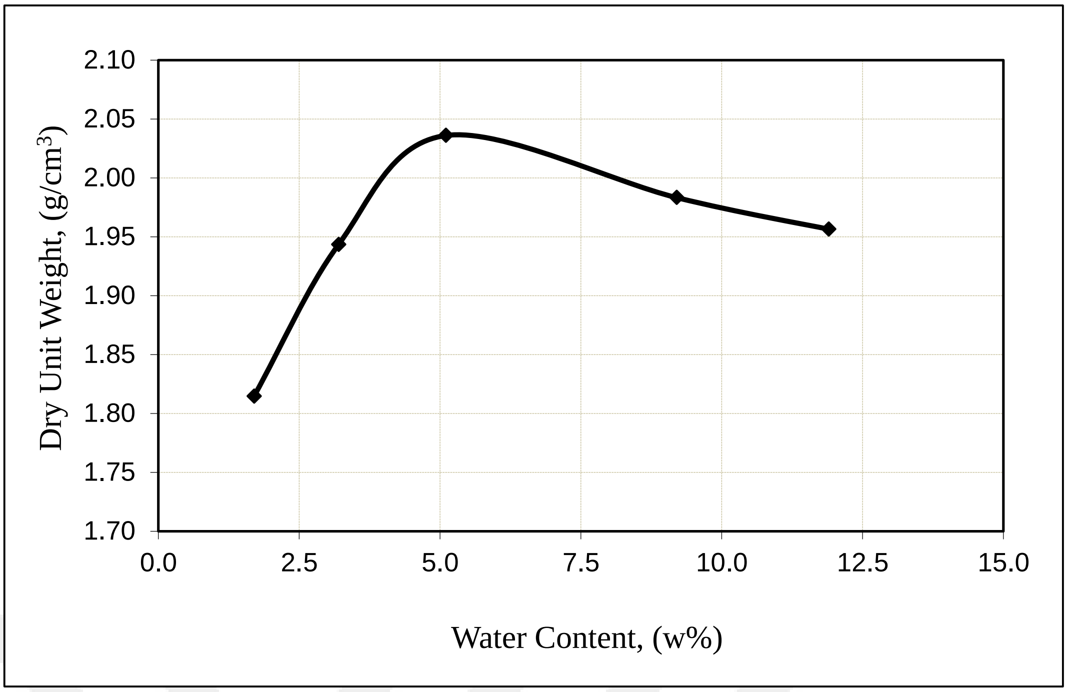

Figure 4.3 Modified Proctor Test result

From the previous modified proctor test result, the maximum dry density was found as 2.04 g/cm^3 and optimum moisture content as 5.4%, the results are compared with previous studies in the Table 4.3. As it can be seen from this table, The RAP samples used in this study had the lowest OMC as compared to others and had the second highest dry density.

Table 4.3 Comparison of compaction test result

Material	Dry Density (g/cm^3)	Optimum Moisture Content (%)	Reference
RAP	2.04	5.4	this study
RAP	2	6.8	Sultan et al. (2013)
RAP	1.88	7.3	Taha et al. (1999)
RAP	2.06	6.5	Hank and Magni (1984)

4.3.3 RAP blends

Six different cases were defined, each having a different mixture ratio of RAP and sand.

Case1: mixed %95 RAP with %5 sand by weight

Case2: mixed %90 RAP with %10 sand by weight

Case2: mixed %85 RAP with %15 sand by weight

Case4: mixed %80 RAP with %20 sand by weight

Case5: mixed %75 RAP with %25 sand by weight

Case6: mixed %50 RAP with %50 sand by weight

In these six different cases Modified Proctor Test was performed and the results were plotted for each case with moisture content percentage in X axis and corresponding dry density value in Y axis. From curves of graphs plotted, there is a optimum point where the value of dry density is maximum. Here corresponding moisture content is the optimum moisture content. Test results are plotted for each case and showed in figure 4.4 – 4.9; the results have revealed that OMC and MDUW were both increasing with decreasing RAP ratio in mixture.

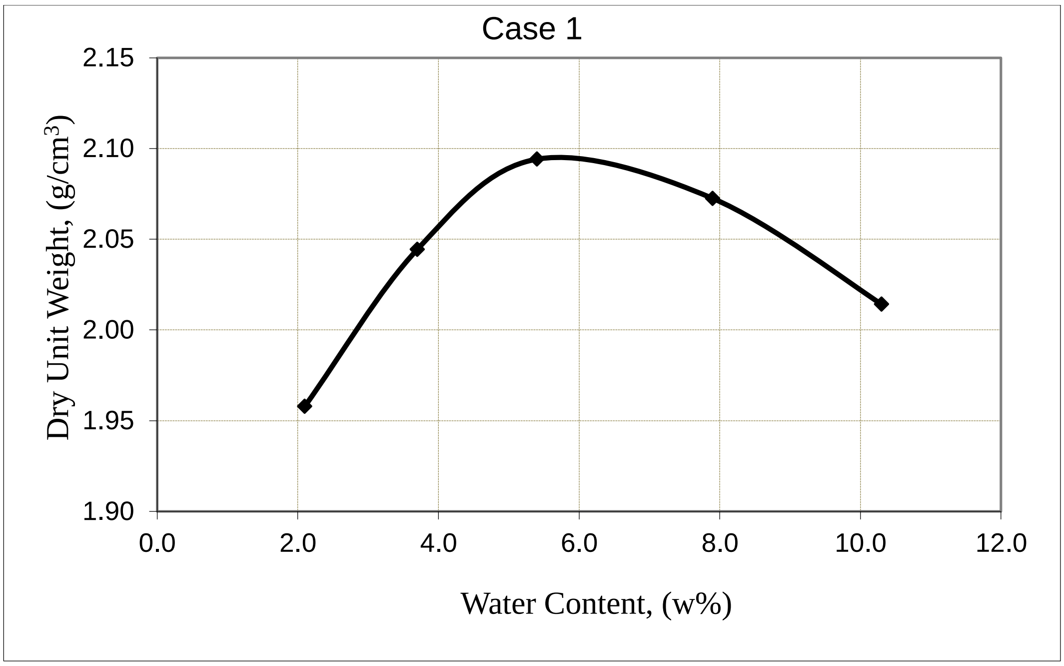

Figure 4.4 Modified Proctor Test result for case 1

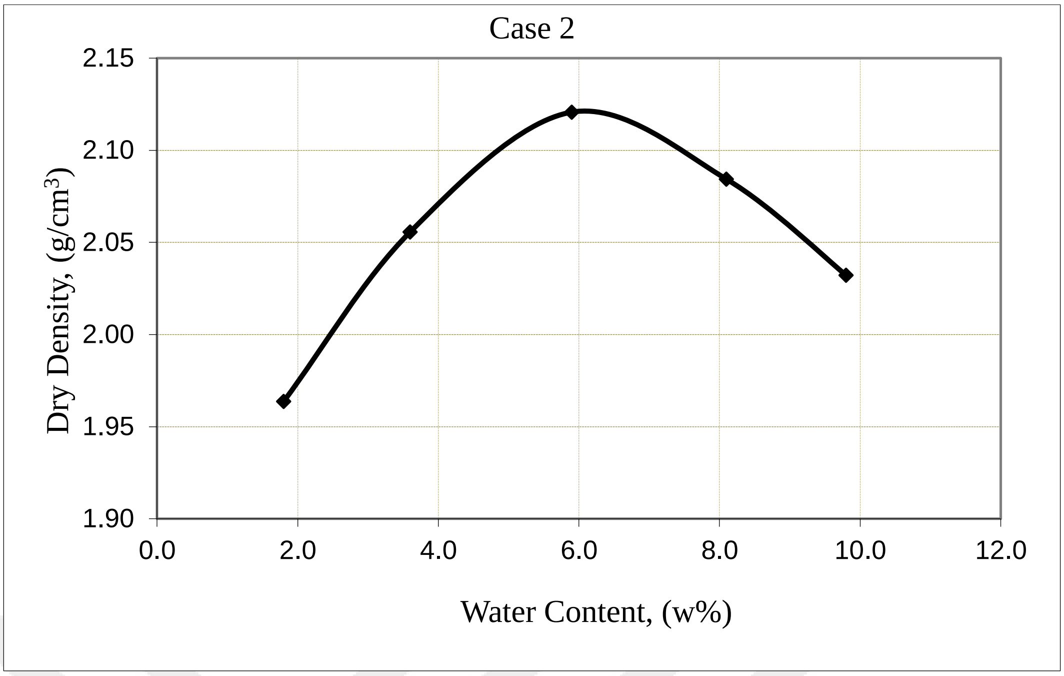

Figure 4.5 Modified Proctor Test result for case 2

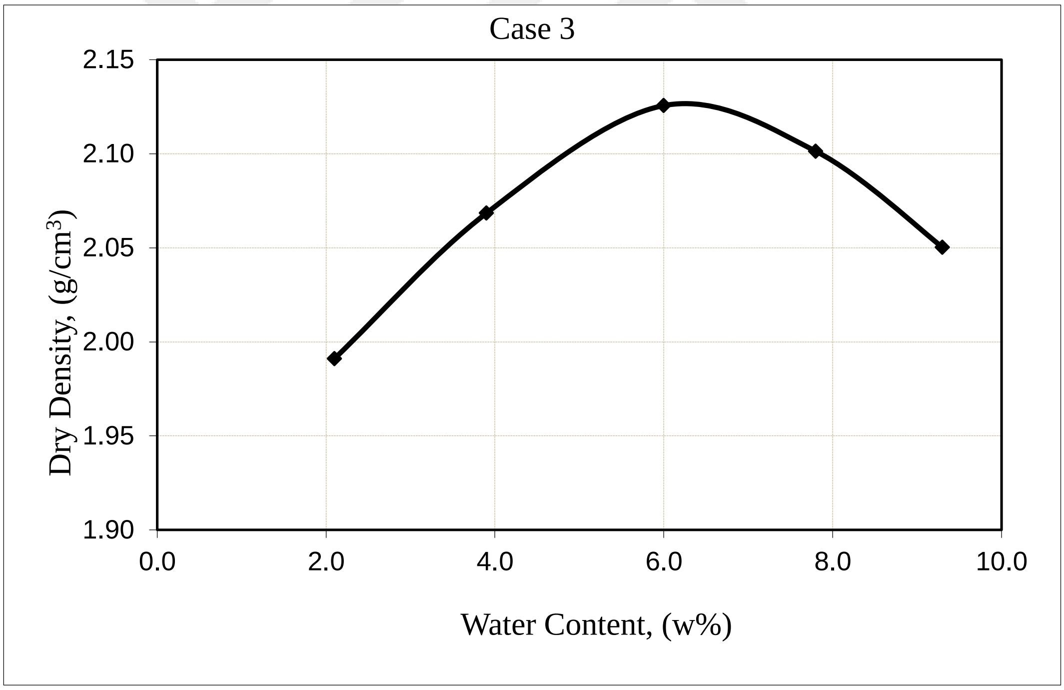

Figure 4.6 Modified Proctor Test result for case 3

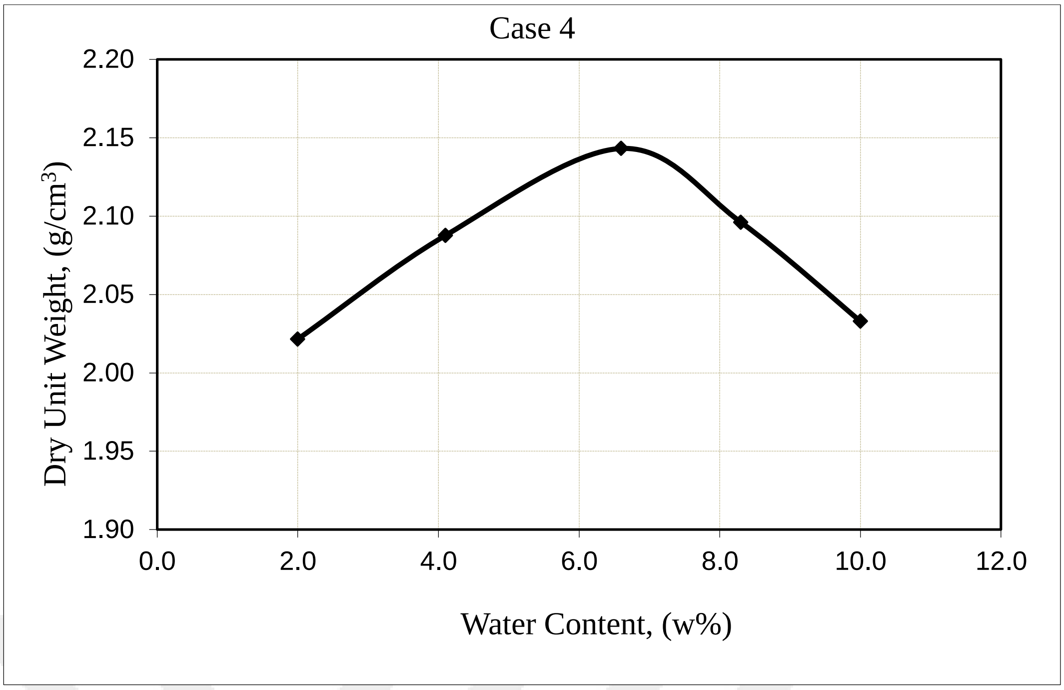

Figure 4.7 Modified Proctor Test result for case 4

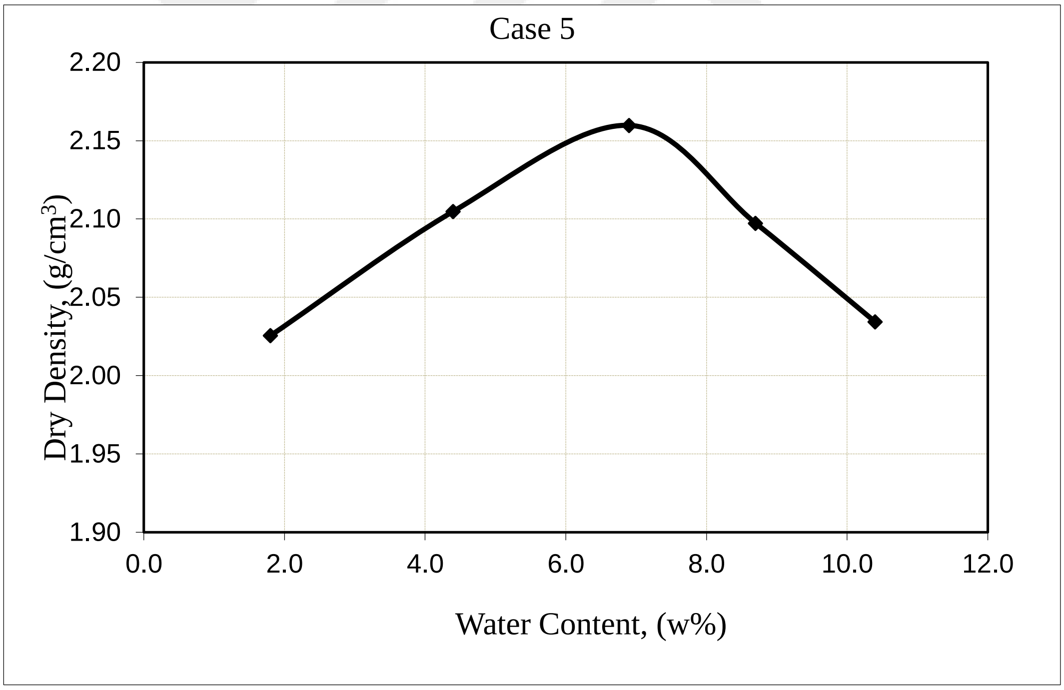

Figure 4.8 Modified Proctor Test result for case 5

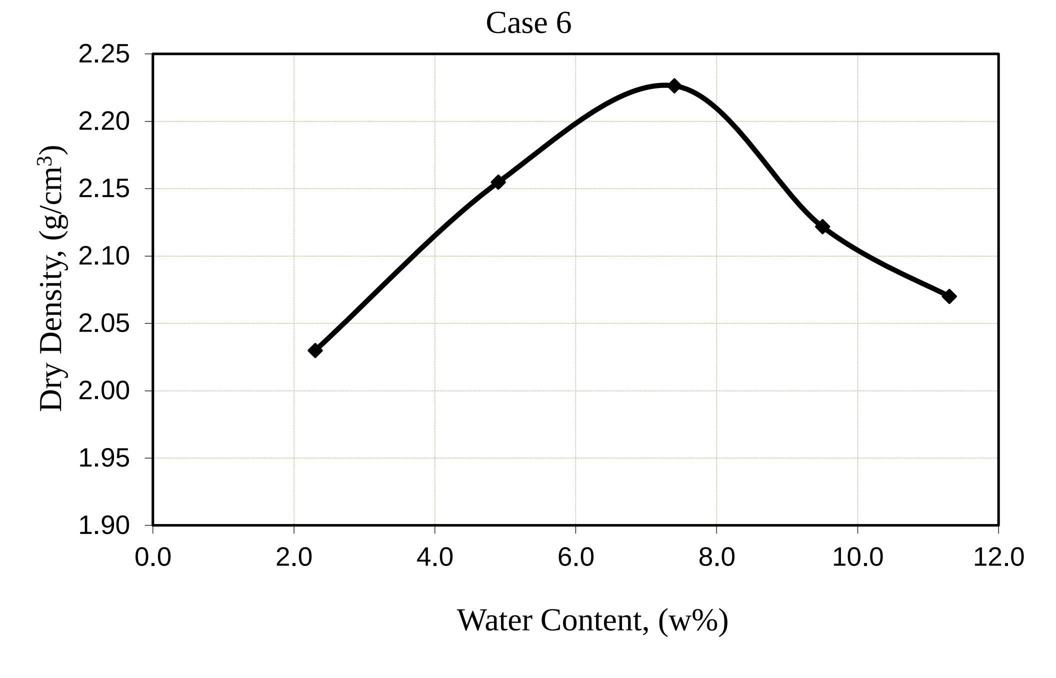

Figure 4.9 Modified Proctor test result for case 6

The variation of the optimum moisture content (OMC) and the maximum dry density (MDD) with various RAP + sand mix proportions are shown in Figure 4.10.

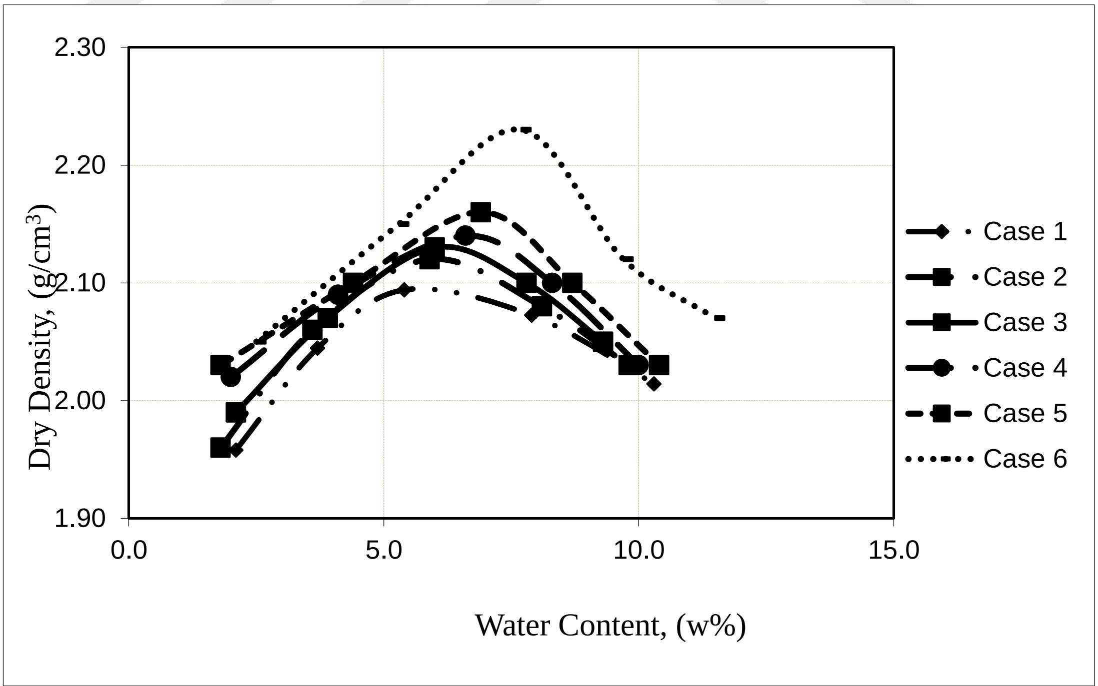

Figure 4.10 Modified proctor comparison graph

The variation of MDD and OMC with increase in percentages of sand are presented in Figures 4.11 and 4.12 respectively

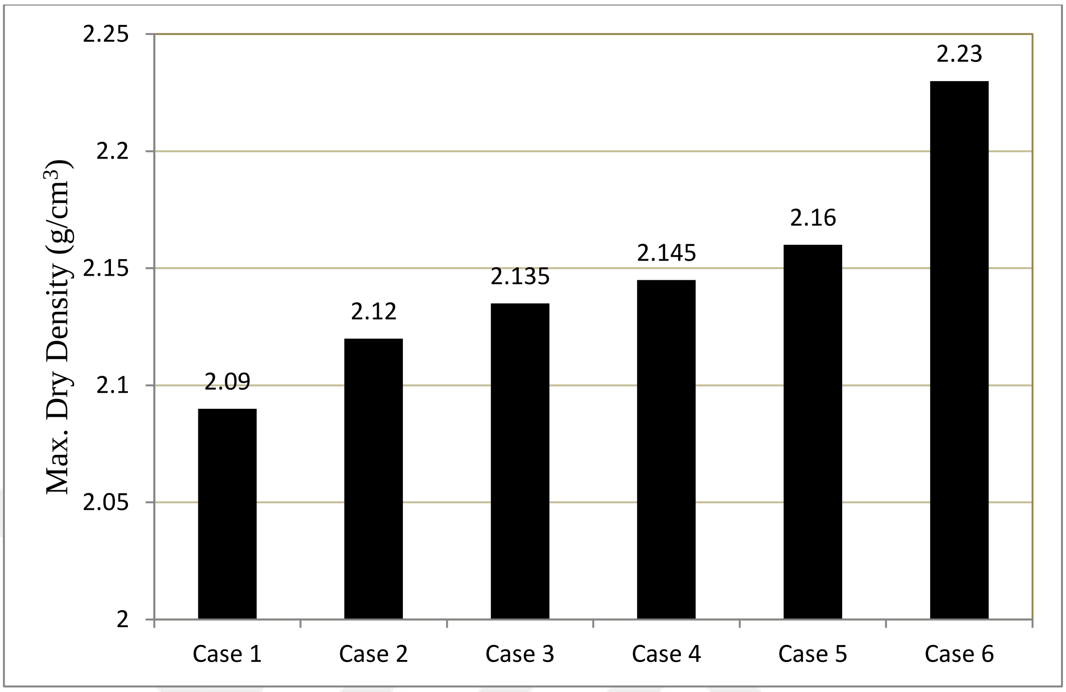

Figure 4.11 Variation of maximum dry density with increasing sand

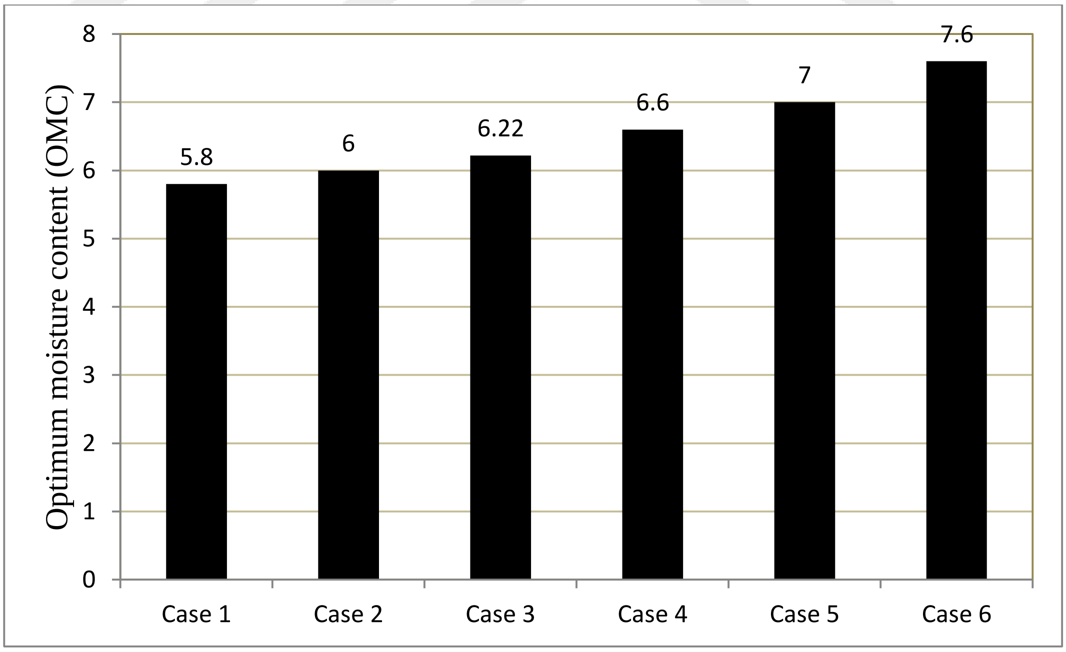

Figure 4.12 Variation of optimum moisture content with increasing sand

These results have clearly shown that the MDUW had increased from 2.09 g/cm^3 to 2.23 g/cm^3 while the OMC had increased from 5.6% to 7.6% for increasing sand ratio of the tested RAP blends. MDD and OMC of RAP blends generally increased with increased sand content, similarly, Guthrie et al. (1999) found that an increase in RAP content led to a decrease in MDD and OMC. Cooley (2005) determined OMC and MDUW for samples containing different percentages of RAP using modified proctor compaction method. The results indicated that the increasing percentage of RAP caused a decrease in OMC and MDUW.

4.4 California Bearing Ratio

The CBR is the measure of resistance of a material to penetration of a standard plunger under controlled density and moisture conditions. This is an extremely normal test to comprehend the subgrade strength before construction of roadways. The test has been broadly researched for the field connection of flexible pavement thickness necessity. Fundamentally testing is carried out according to ASTM D 1883. The test comprises of bringing on a round and cylindrical plunger of 50mm diameter to penetrate a pavement part material at 1.25mm/minute. The loads, for 0.5mm, 1mm, 1.5mm, 2mm, 2.5mm….., 5mm, 5.5mm, 6mm….., up to 12mm to 13 mm are recorded in every 0.5mm of gaping. Penetration in mm are plotted in X axis and load expressed in kg with corresponding points are plotted in Y axis and prepare graph for different specimen.

The CBR values at 2.5mm and 5.0mm penetrations are calculated for each specimen from the corresponding graphs which is shown below. Generally the CBR value at 2.5mm penetration is higher and this value is adopted. CBR is defined as the ratio of the test load to the standard load, expressed as percentage for a given penetration of the plunger. This value is expressed in percentage. Standard load of different penetration is discussed before.

Here soaked and un-soaked CBR test were carried out according to ASTM D 1883 standard. The corresponding CBR value for each specimen is written on left above corner of each graph. The effect of sand content on CBR value of RAP mixtures were investigated through these experiments.

4.5 Un-soaked CBR Tests

4.5.1 Sand

Un-soaked CBR test was performed on sand sample at optimum moisture content (9.8%), The CBR result for sand sample is shown below in Figure 4.13

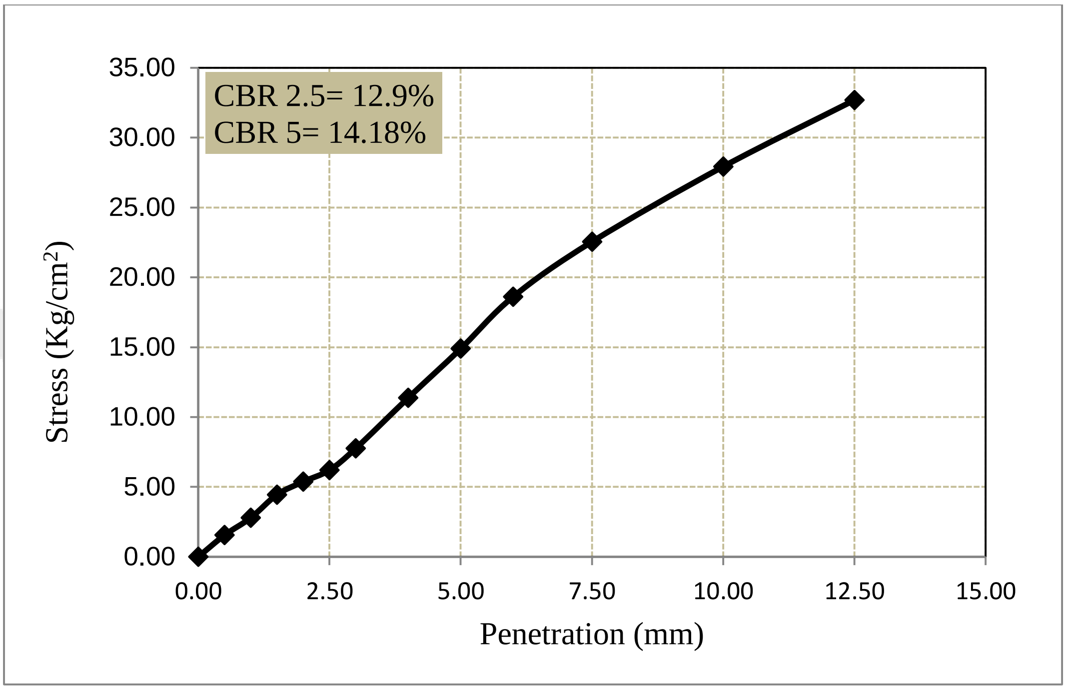

Figure 4.13 Penetration versus stress relationship obtained from CBR test

4.5.2 Reclaimed Asphalt

Un-soaked CBR test was performed on RAP sample at optimum moisture content (5.1%), the result of RAP sample is shown in Figure 4.14.

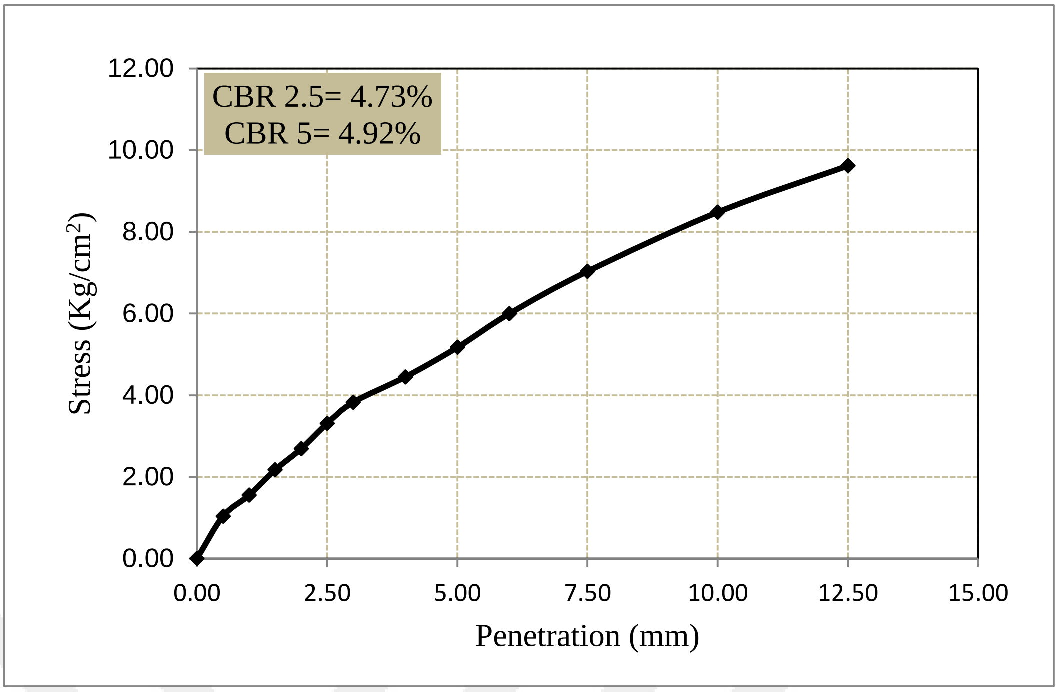

Figure 4.14 Penetration versus stress relationship obtained from CBR test

The CBR values presented for in previous studies for 100% RAP samples are listed below in Table 4.4, the results indicated that the RAP samples tested in this study had the lowest CBR value as compared to others.

Table 4.4 Comparison of CBR test result

Material	CBR (%)	Reference
RAP	4.92	this study
RAP	6	Sultan et al. (2013)
RAP	11	Taha et al. (1999)
RAP	13	Hank and Magni (1984)

4.5.3 RAP Blends

CBR test were conducted on six cases defined of the previous of these chapter, at maximum dry density and optimum moisture content. The test results are plotted below from Figure 4.15 to Figure 4.20.

Case 1:

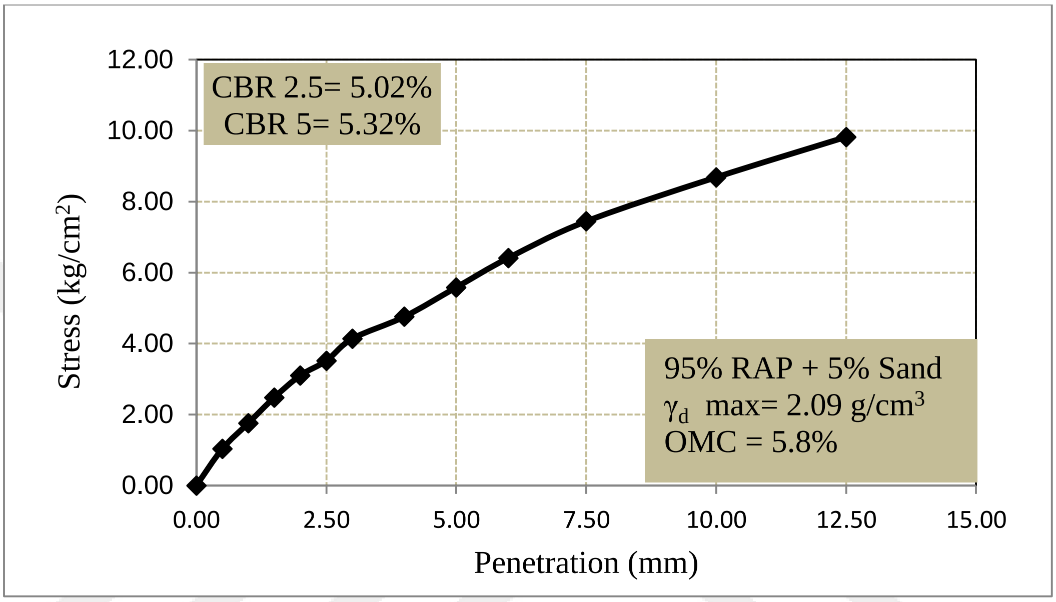

Figure 4.15 CBR test result, case 1

Case 2:

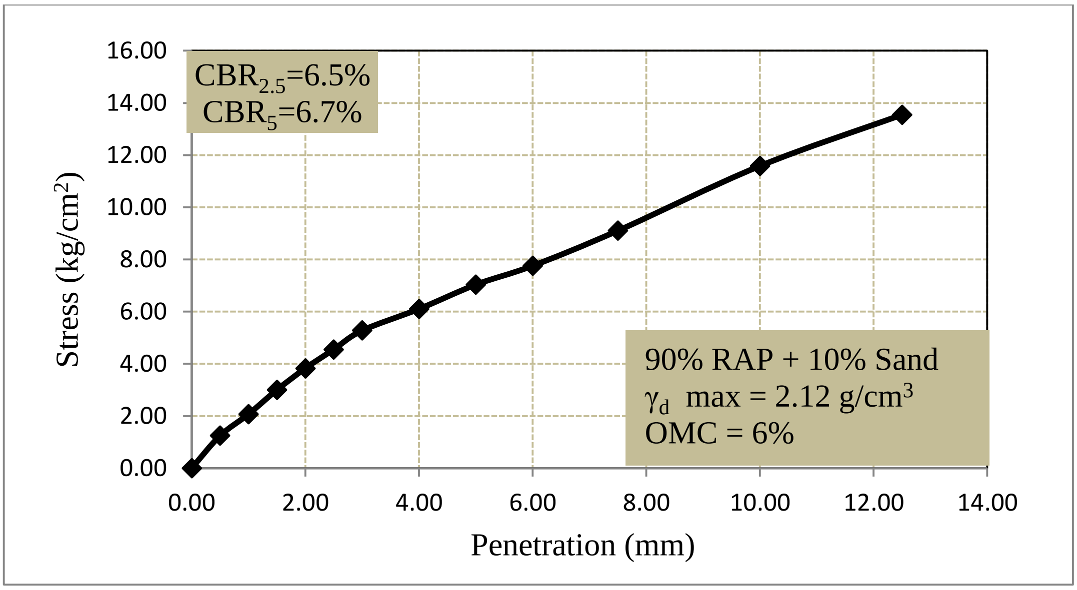

Figure 4.16 CBR test result, case 2

Case 3:

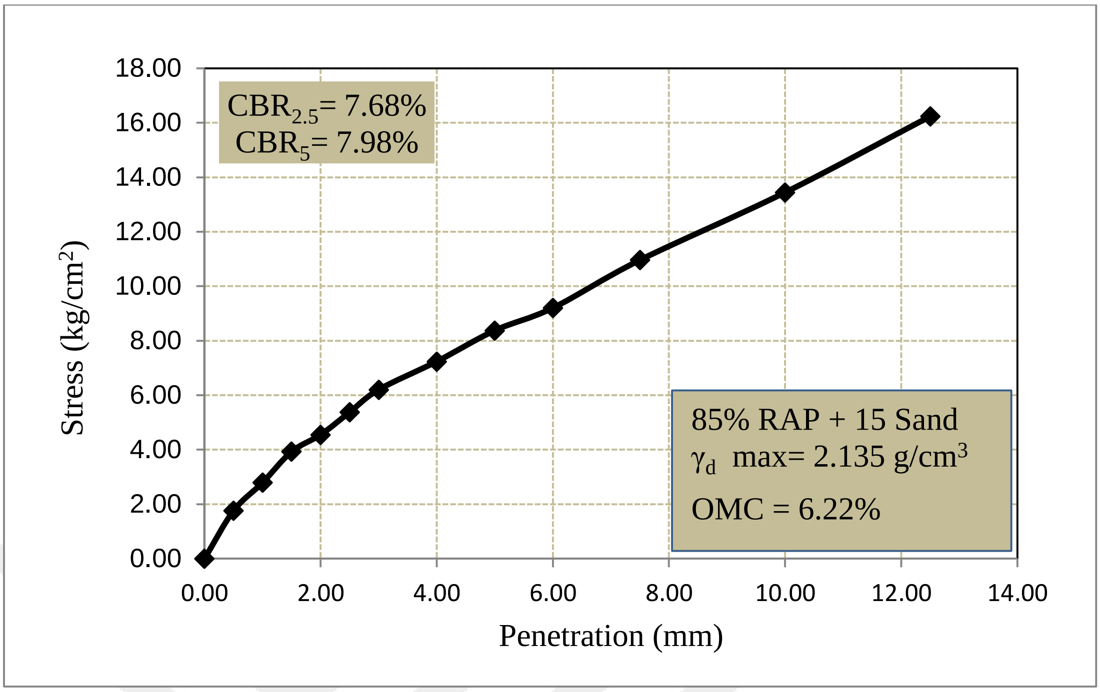

Figure 4.17 CBR test result, case 3

Case 4:

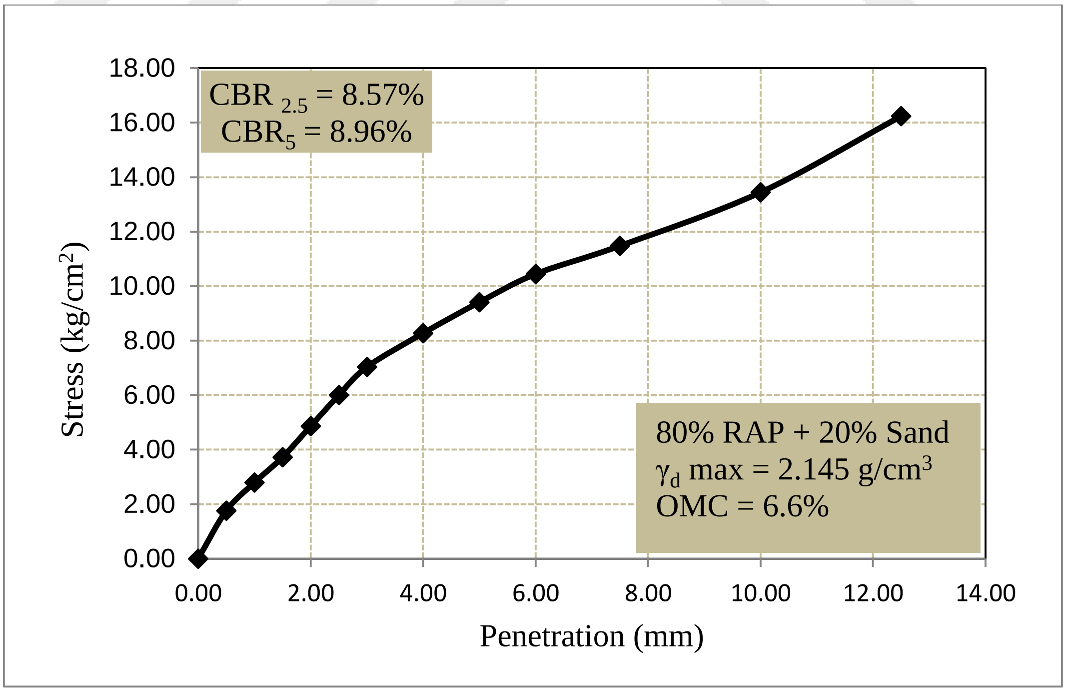

Figure 4.18 CBR test result, case 4

Case 5:

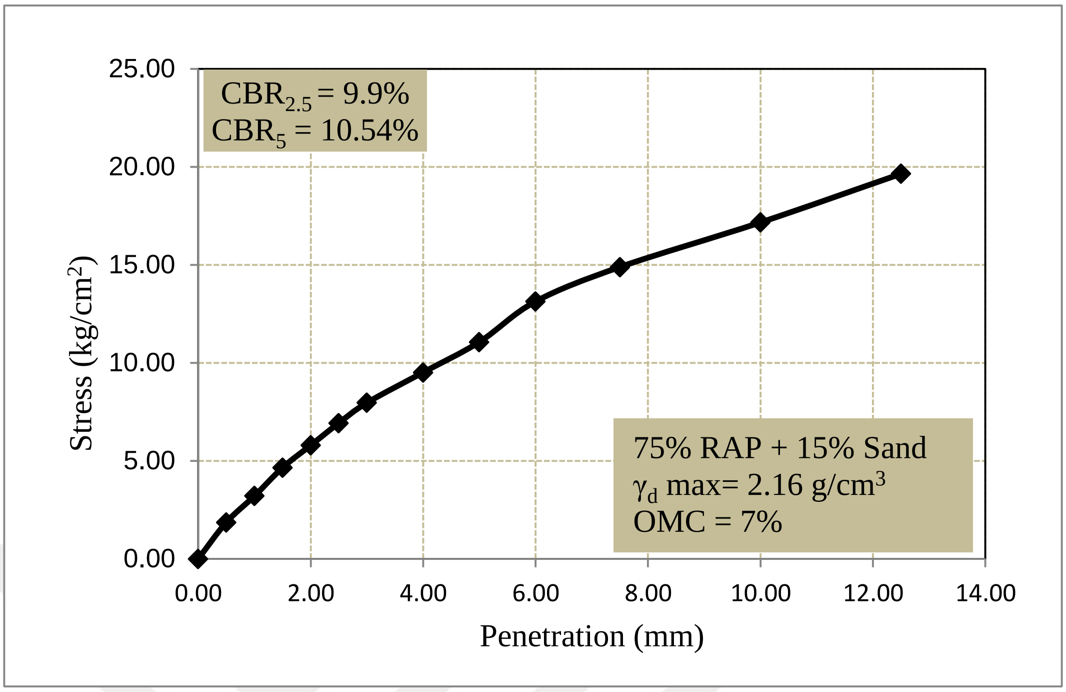

Figure 4.19 CBR test result, case 5

Case 6:

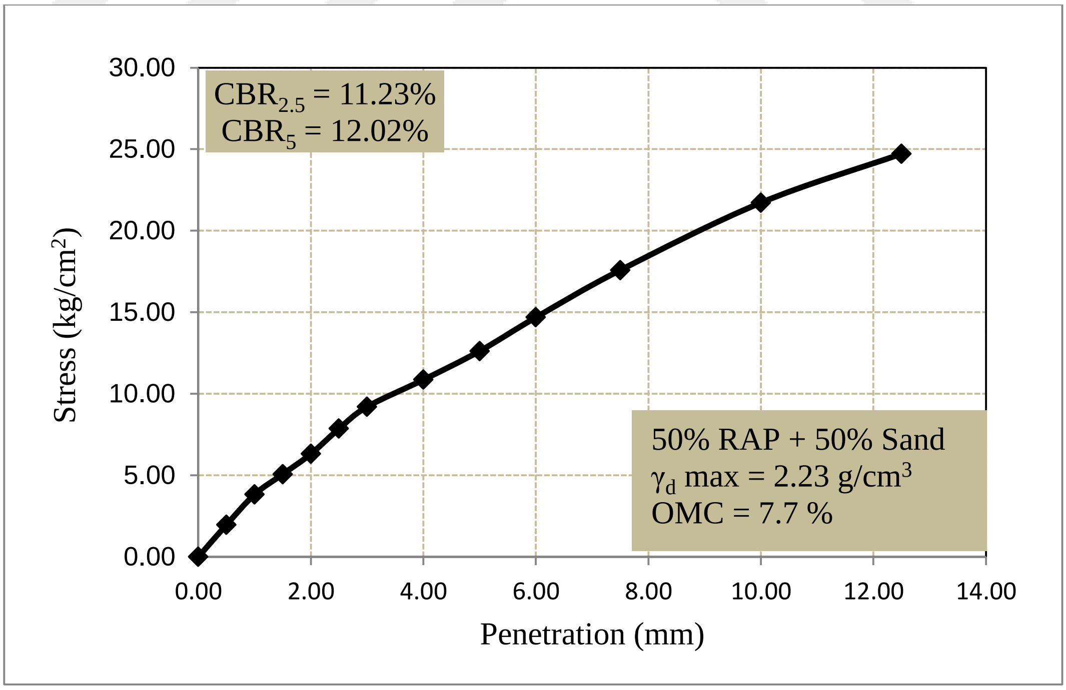

Figure 4.20 CBR test result, case 6

The variation of un-soaked CBR with increasing percentages of sand is presented in Figure 4.21.

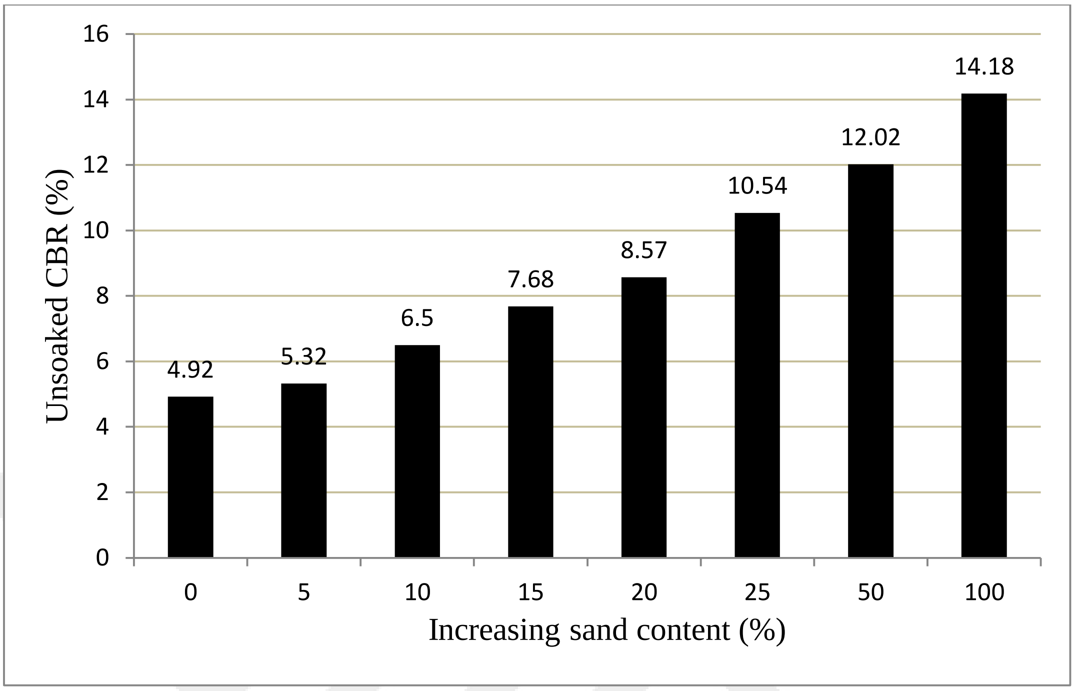

Figure 4.21 Variation of un-soaked CBR with increasing percentage of sand

From the previous CBR test result, it was showed that %100 percent of RAP has lowest CBR value (4.92), as the percentage of sand in the mixture increases, the CBR value increases. When 20% sand is added to RAP, The CBR values increases to 8.57. The possible reasons for increasing in CBR may be due to better load transfer between the sand particles and the slip surfaces developed between the asphalt-coated particles of the RAP. In addition, by increasing the content of sand in the mix, better interlocking between aggregate particles will develop. This will lead to further increases in the shear strength of the blend.

4.6 Soaked CBR Tests

Soaked CBR tests were carried out for each cases, after five days of soaking, the decrease of CBR values as compared to the unsoaked case was on the order of 8% for the tested cases independent of the sand percentage**,** the results are given in Figure 4.22 to Figure 4.27.

Case 1:

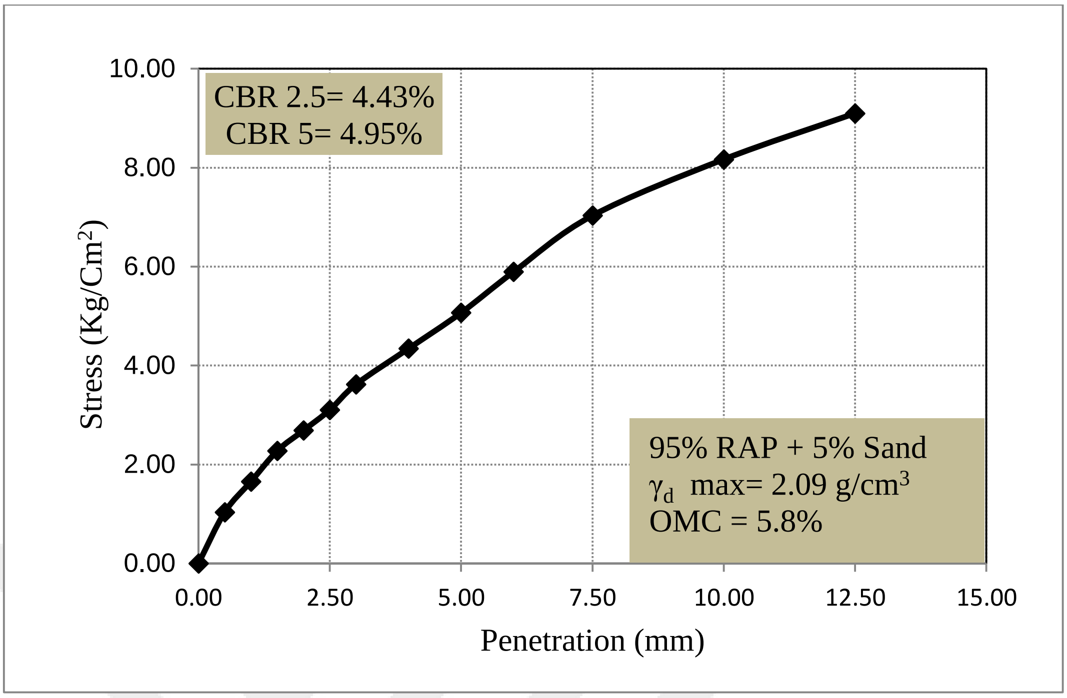

Figure 4.22 CBR test result, case 1

Case 2:

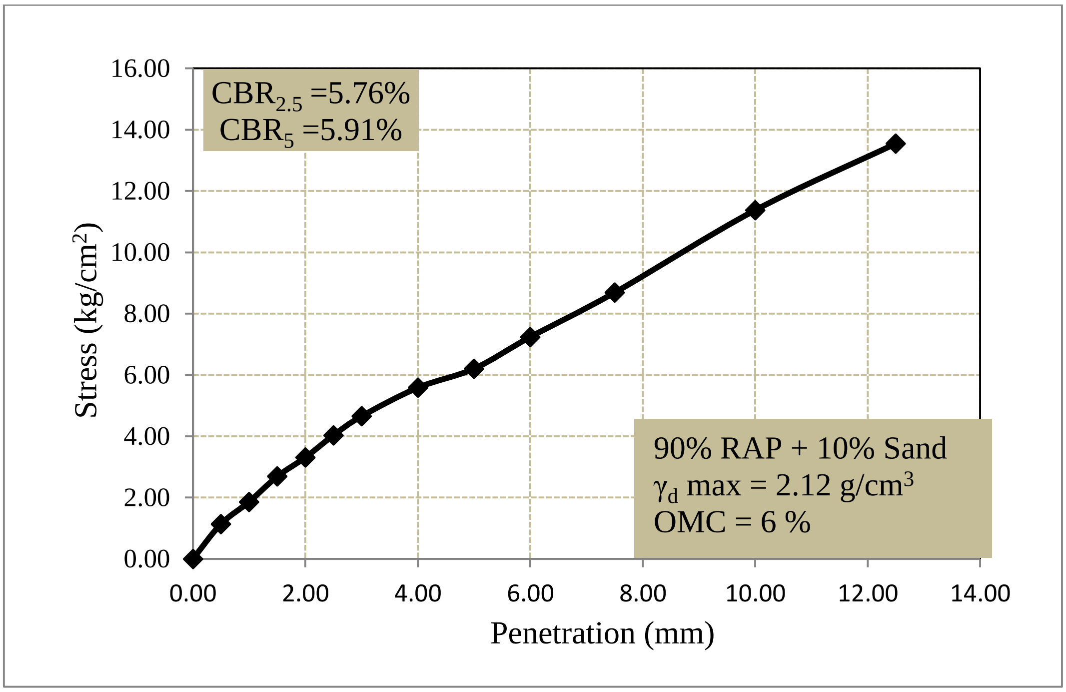

Figure 4.23 CBR test result, case 2

Case 3:

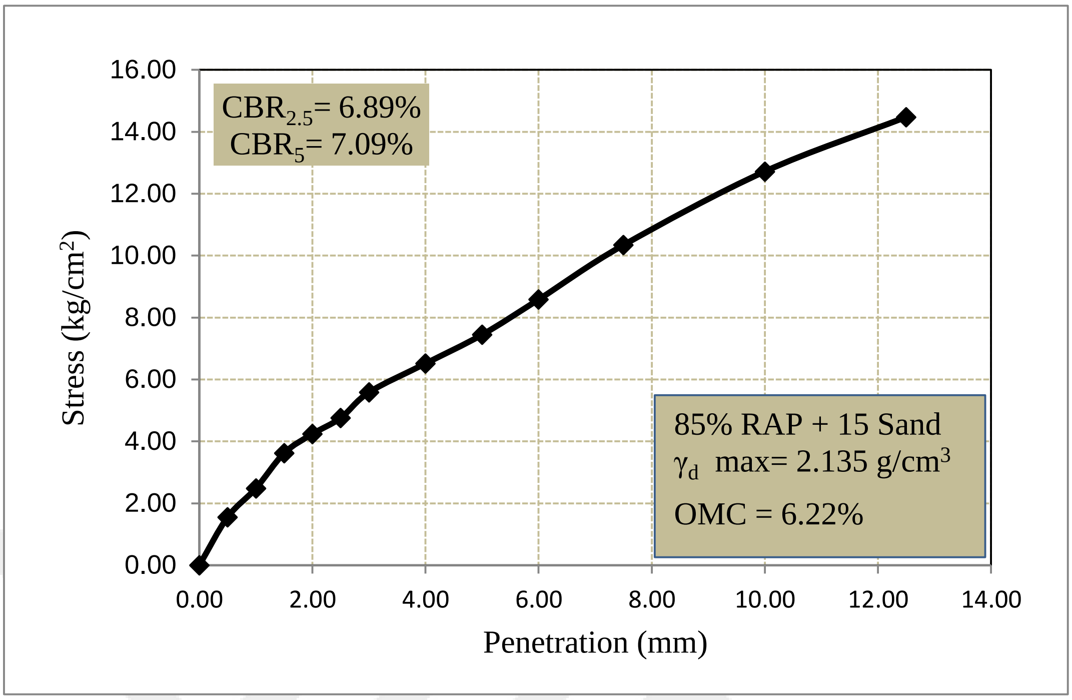

Figure 4.24 CBR test result, case3

Case 4:

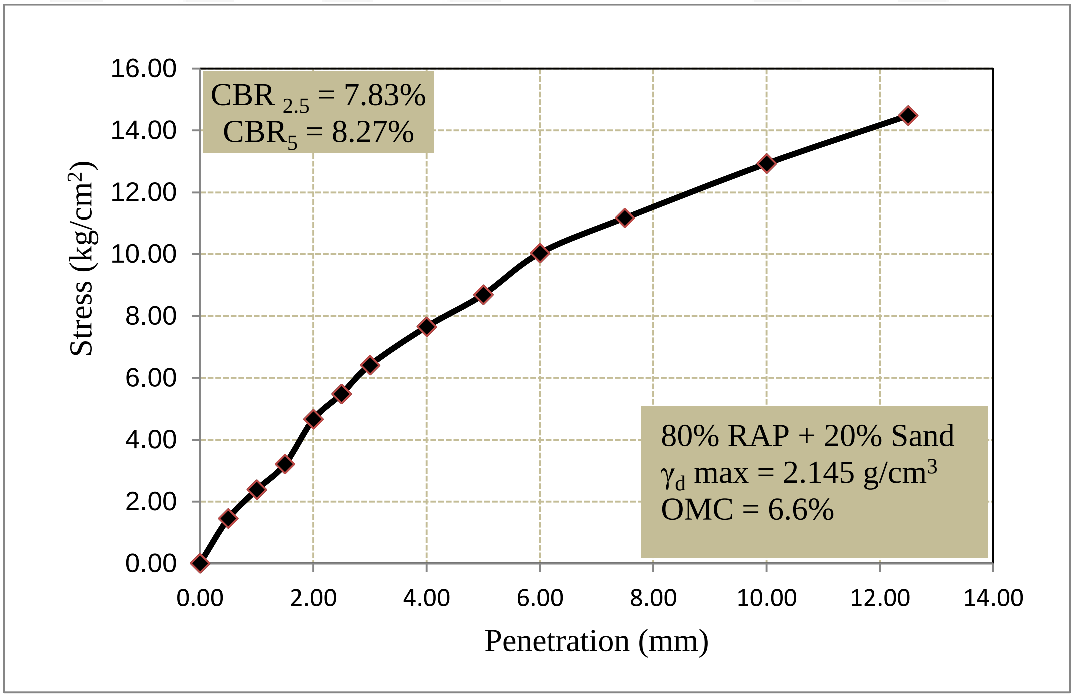

Figure 4.25 CBR test result, case 4

Case 5:

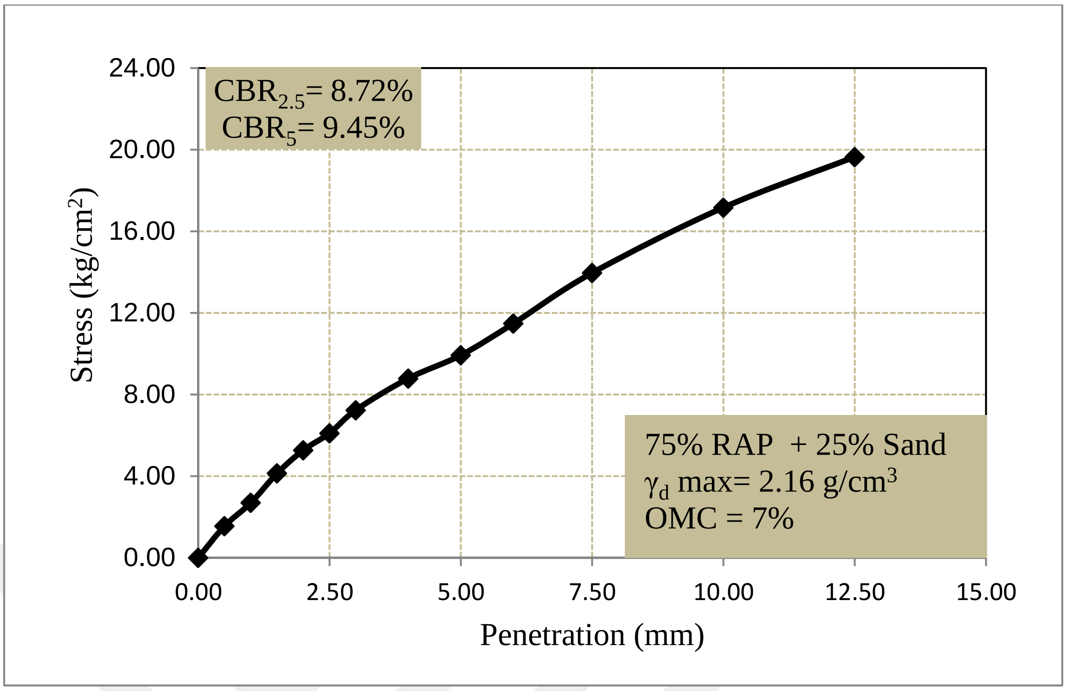

Figure 4.26 CBR test result, case 5

Case 6:

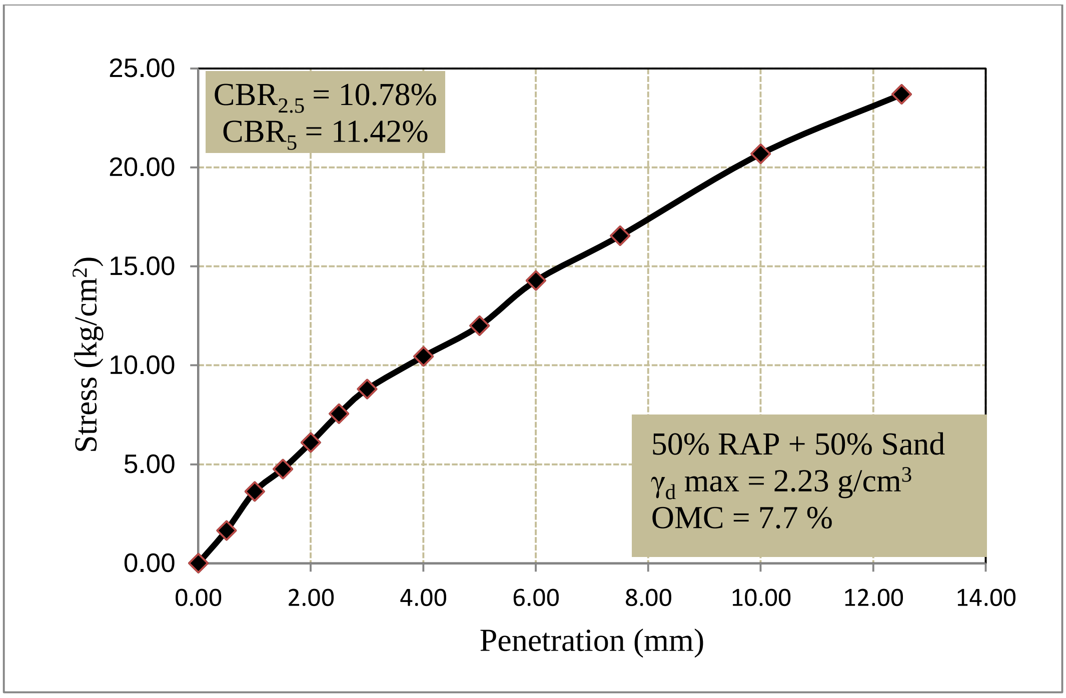

Figure 4.27 CBR test result, case 6

The variation of soaked CBR with increasing percentages of sand is presented in Figure 4.28.

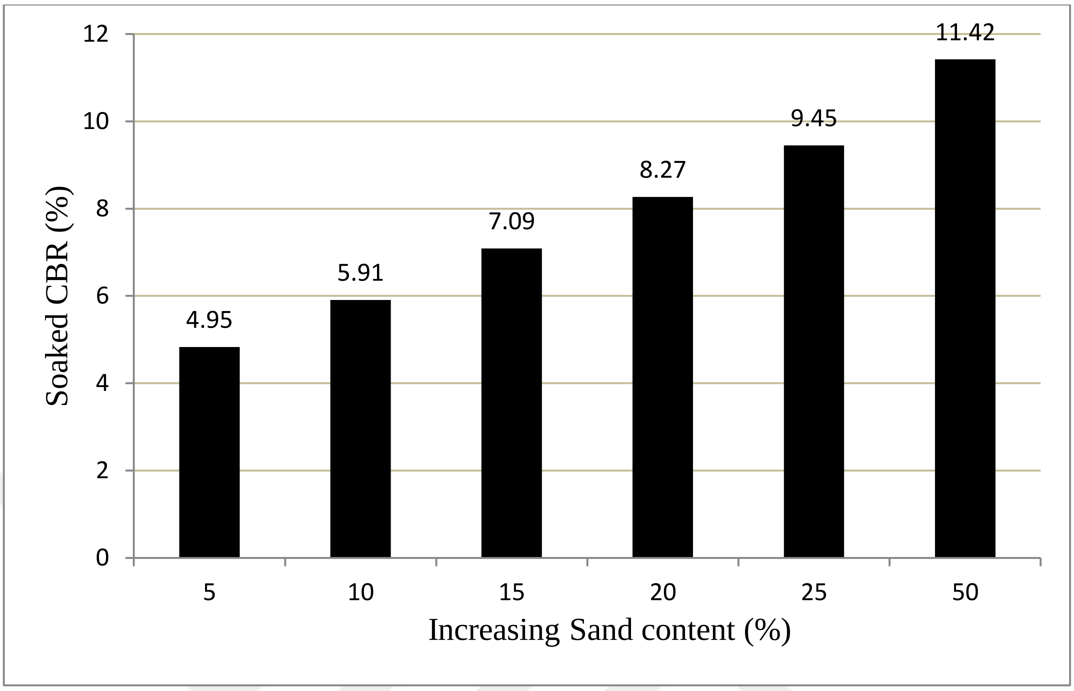

Figure 4.28 Variation of un-soaked CBR with increasing percentage of sand

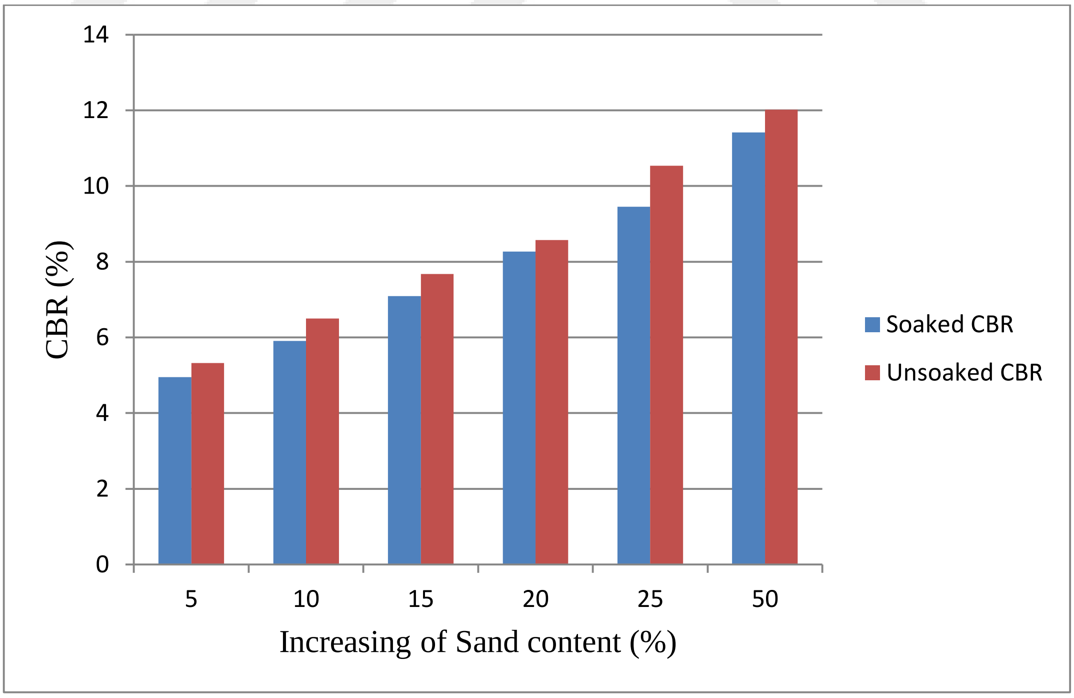

Figure 4.29 Comparison of un-soaked & soaked CBR result with increasing sand

CHAPTER 5

CONCLUSIONS

Reuse of non-renewable resources and to reduce the size of the stockpiles of RAP both can be accomplished by using RAP as base and subbase, layers and are both beneficial for sustainable construction.

In this study, the RAP collected from three different places and mixed with sand at different ratio were tested to find out the compaction, CBR properties and possibility use of mixture as base and subbase layers. Based on the laboratory results from this research project, the following conclusions can be derived:

1. RAP derived from different sources has different density, water absorption and compressive strength characteristics.

2. According to particle size distribution, RAP was classified as poorly graded gravel with sand while the sand samples were classified as poorly graded sand.

3. The maximum dry density of the tested samples increased gradually by increasing sand content, the maximum dry density was found to be 2.04 g/cm^3 for 0% sand while it was 2.23 g/cm^3 for 50% sand ratio, making a change on the order of 9% between two extreme points.

4. The optimum moisture content of RAP mixed with varied percentage of sand increased from 5.4% at 0% of sand to 7.6% at 50% of sand, this represent a 40.7 % increased in OMC.

5. The un-soaked CBR value increased significantly with increasing sand ratio as compared to 100% RAP sample, such that the CBR value was measured as 4.92% for 100% RAP samples while it was 12.02% for mixtures with 50% RAP and 50% sand, the increase is 144%.

6. The soaked CBR value of the tested samples increased gradually by increasing sand content, the CBR value was found to be 4.92 % for 0% sand while it was

11.42% for 50% sand ratio, this makes a change on the order of 132% between two extreme points.

7. The obtained results are mostly in accordance with the literature data for the change in dry density, moisture content and CBR values (which is increasing these values with increasing the virgin aggregate).

8. None of the samples met the requirements in the meaning of CBR values, to be used as a base or subbase materials according to AASHTO Standards (Min. CBR values for subbase 30%. for base 80% according to AASHTO Standards).

9. More than 20% of sand content can be blended with RAP for used as an embankment (Min CBR values for embankment 8% according to AASHTO Standards).

5.1 Recommendation:

1. Stabilization of RAP with Portland cement may be studied to improve material strength.

2. Blending RAP with other aggregates such as crushed stone, gravel or limestone may be studied.

3. Durability of RAP material in base or subbase layers.

CHAPTER 6

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APPENDEX

APPENDEX A: Photographic views

Figure A.1 Photographic view of shaqlawa street

Figure A.2 Photographic view of mosul street

Figure A.3 Photographic view of maxmwr street

Figure A.4 Modified compaction test

Figure A.5 Sample after compaction test

Figure A.6 Soaked CBR sample in water

Figure A.7 CBR test device

Figure A.8 Sample after the CBR test