

**ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES**

MSc THESIS

Hamadou Lamido SALIFOU

**INVESTIGATION OF USING RECLAIMED ASPHALT
PAVEMENT (RAP) AS A ROAD SUB BASE AND BASE
COURSE MATERIAL**

DEPARTMENT OF CIVIL ENGINEERING

ADANA, 2018

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INSTITUTE OF NATURAL AND APPLIED SCIENCES**

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ABSTRACT
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**ÇUKUROVA UNIVERSITY
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DEPARTMENT OF CIVIL ENGINEERING**

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Year: 2018 Pages: 105
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The objective of this study is to investigate and examine reclaimed asphalt pavement (RAP) material and different RAP/virgin aggregate blending techniques that can improve the mechanical characteristics of local RAP materials to meet the specification of afnor (French Association for Standardization) for road subbase and base course characteristics. A detailed laboratory testing program was conducted to achieve these objectives. It was found that the blending of up to 30% RAP materials with local virgin sub-base and base materials improves the RAP mechanical characteristics to meet requirements for road sub-base, base materials and provides economical, environmental, and sustainable road construction alternatively technique.

Keywords: Mechanical Properties, RAP, Particle size, Proctor, Atterberg, California Bearing Ratio (CBR);

ÖZ
YÜKSEK LİSANS TEZİ

**ATIK ASFALT MALZEMESİNİN, YOL ALT VE ANA TABAKA
MALZEMESİ OLARAK KULLANILMASININ ARAŞTIRILMASI**

Hamadou Lamido SALIFOU

**ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
İNŞAAT MÜHENDİSLİĞİ ANABİLİM DALI**

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Yol yapımı için Asfalt Kaplamanın Geri Dönüşümü (RAP) tekniği yaygın olarak kullanılmaktadır, böylelikle RAP, dünyadaki en kullanılan dönüşümlü malzeme olarak adlandırılmaktadır. RAP genellikle asfalt karışımında bir agrega ikame maddesi olarak da kullanılır. Ayrıca granüller alt baz veya baz agrega ve dolgu veya dolgu malzemesi olarak kullanılır. Ne yazık ki, RAP malzemelerinin mekanik özellikleri, alt tabaka ve temel agrega malzemelerinin özelliklerini karşılamamaktadır. Bu çalışmanın amacı, yerel RAP materyalinin mekanik özelliklerini geliştirmek için RAP ve farklı RAP / ham agrega harmanlama tekniklerini araştırmak ve incelemektir. Bu amaçlara ulaşmak için detaylı bir laboratuvar test programı uygulandı. % 30'a varan RAP materyalinin yerel ham alt tabaka ve temel malzemelerle harmanlanmasının, yol alt tabakası, temel materyalleri gereksinimlerini karşılamak için RAP mekanik özelliklerini geliştirdiği ve ekonomik, çevresel ve sürdürülebilir yol yapım tekniği sağladığı bulundu.

Anahtar Kelimeler: Mekanik Özellikler, Geri kazanımlı Asfalt Yol (RAP), Harmanlama teknikleri, Parçacık boyutu, Proctor, Atterberg, California Bearing Ratio (CBR);

EXTENDED SUMMARY

This report presents research findings from the investigation of using Reclaimed Asphalt Pavement (RAP) as road sub base and base materials. The objectives of this report is:

1. To investigate and examine RAP material and different RAP/virgin aggregate blending techniques to improve the mechanical characteristics of local RAP materials;
2. Describe the test methods used and the results obtained from the testing.
3. Provide conclusions and recommendations relating to the amount of RAP to be used for blending;

The research was managed and performed by the Geotechnical Branch of SNER road construction company. The laboratory work was consisted of the following tasks: Testing of virgin material, reclaimed asphalt and blended materials to obtain the values for each of the following test parameters: Gradation, Plasticity Index (PI), Density, Unit weight, Optimum moisture and CBR index.

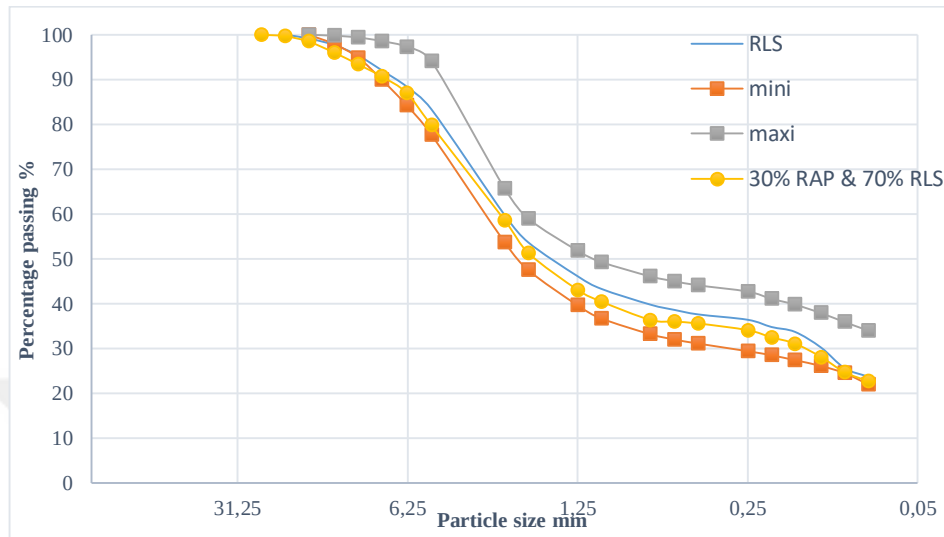
Laboratory works procedure:

Before testing the Reclaimed Asphalt, it was essential to make a complete identification of the virgin materials used in the road subbase, base layers to have the exact values which will constitute a reference to compare the values of reclaimed asphalt.

The work was carried out in two stages for each test: the first step is testing the local virgin aggregate to determine the properties and the second step was to test the chosen blended materials and compare the results.

The conclusions as a function of the tests carried out are as follows:

Particle Size Distribution Test for Reclaimed Asphalt - NF P 94 056



The blending of RAP by adding different percentage of virgin materials allows the curve to progress towards the mini and maxi curves. As shown in the graphic table, the mixture of 30% reclaimed asphalt and 70% laterite gives us a curve closest to the curve of the representative sample. The material '30% RAP and 70% lateritic' gives us a curve that has a distribution of particles appropriate to the subbase layer of a road according to standard NF P 94-056, Therefore the material '30% RAP and 70% lateritic' will be our materials on which we will conduct the different tests. The tests conducted on the '30% RAP and 70% laterite' will be compare to the different result lead on the representative sample of the laterite.

Atterberg Limit (w I) – NF P 94 – 051

The plasticity index $I_p = W_L - W_P$ allows us to characterize the clay content of a soil. According to the GTR classification, $0 < IP < 12$ low clay content. According to this classification the two materials contain little clay and are in the same class.

WL	WP	IP
25,1	19,2	5,9

Modified Proctor Compaction Test - NF P 94 – 093

The results of the modified proctor test show that the blended material and the virgin material RLS have almost the same behavior of relationship between the moisture content and the dry density. This also proves that the mixed material agrees with the material standard used in road construction.

Materials	W%	δd KN/m ³
RLS (Representative sample of laterite)	7,30	21,03
Blended material (30 %RAP and 70% RLS)	7,60	21,10

C B R (California Bearing Ratio) imbibed at 4 day - NF P 94 – 078

Results Interpretation of the CBR test for the two materials:

The CBR values and the density values of the two materials, we observe approximately the same values. On the other hand, for the swelling values, we observe that the blended material resists more with very minimal swelling values which is perfectly expected because the asphalt doesn't absorbed water.

CBR soaked			N.	δd KN/m ³	CBR Index		Moisture content	swelling%
					Unsoaked	soaked		
90%	95%	100%	55	21,1		103,7	8,2	0,01
33	60,0	103,7	25	20,1		60	8,5	0,01
			10	19		33	9,4	0,02

In conclusion the blended material fulfilled the specifications of the materials usable in the subbase layer of a road.

The laboratory work allowed us to make a complete analysis of laterite as (virgin materials) and compare it to our blended material (waste material). As detailed in the previous steps we have made 4 (four) primordial geotechnical tests in road construction in tropical areas, the tests conducted are: particle size distribution test, atterberg limits, modified Proctor and CBR test.

The results of the tests on the laterite and those of the blended material have been compared and have given approximatively the same results, it allows us to conclude that our blended material can be used safely in road construction in the tropical zones.

NB: The same procedure was made for the road base material.

ACKNOWLEDGEMENT

I would first like to thank my thesis Supervisor Assoc. Prof. Ali Hamza TANRIKULU, the door to Assoc. Prof. Ali Hamza TANRIKULU office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

I would also like to thank the technical branch of SNER company/Chad which allowed me to work free in their laboratory. I also do not forget all the help and advice of the Çukurova university laboratory team. Without their passionate participation and input, the thesis would not have been successfully conducted.

I would also like to acknowledge Prof. Dr. Abdulazim YILDIZ, Assist. Prof. Dr. Baki BAĞRIAÇIK, Res. Ast Mustafa TOLUN as the second readers of this thesis, and I am gratefully indebted to them for his very valuable comments on this thesis.

Finally, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

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1. INTRODUCTION

1.1. Background

Nowadays the waste management is a key issue with the delicate context of natural resource aggregates and limited prospects for the storage of waste. This has resulted in increased research in transportation geotechnics to study the viability of reusing all categories of solid waste. The solid waste is generated by construction and demolition (C&D) or commercial and industrial activities. Construction and demolition (C&D) materials are the excess or waste materials associated with the construction and demolition of buildings and structures, including concrete, brick, reclaimed asphalt, steel, timber, plastics.

To the question how much waste we produced in the world? Here are some details of the Cyclops annual report.

Estimates of world production of waste is 3.4 to 4 billion tons per year. The volume of waste in the world has increased in the first half of 2009 from 5 to 10% of total annual volume from 3.4 to 4 billion tons, of which:

- From 1.7 to 1.9 billion of municipal waste: in 2012, three billion urban dwellers produced 1.3 billion tons of solid waste per year (1.2 kg / person / day), and in 2025, this volume will be 2.2 billion tons (1.42 kg/person/day) generated by 4.3 billion urban in the world. This corresponds to an increase of 70% of municipal solid waste by 2025,
- From 1.2 to 1.67 billion non-hazardous industrial waste
- 490 billion kilograms of hazardous waste.

In this way, the urgent need for reusing is of global concern and is driven mainly by environmental considerations, due to the increasing scarcity of natural resources and the growing disposal cost into the landfills in many countries. It is

widely accepted that recycling and subsequent reuse of C&D materials will reduce the demand for scarce virgin natural resources and simultaneously reduce the quantity of this waste material destined for landfills.

These figures also indicate that removing the obstacles for the reuse of C&D materials in road work and pavement applications through research will have a profound impact in moving toward a more sustainable global environment.

1.2. The Scope of Study

Most of highways and roads in the world are constructed with Hot Mix Asphalt. As the infrastructure ages, these highways and roads must be maintained and rehabilitated.

The technical increment and improvement of the milling machine within the last few years had produced increasing amounts of reclaimed asphalt (RAP) materials. These amounts of RAP were accumulated due to the milling of old asphalt pavements of roads. The Federal Highway Administration estimates that 100 million tons of hot mix asphalt is milled each year in the United States only (MAPA, 2007), as a result of this practice a tremendous amount of Reclaimed Asphalt Pavement (RAP) is created every year, and over 80% of RAP was recycled, making asphalt the most frequently recycled material.

Reclaimed asphalt pavement (RAP) is most commonly used as an aggregate and virgin asphalt binder substitute in recycled asphalt paving, but it is also used as a granular base or subbase, stabilized base aggregate, and embankment or fill material. It can also be used in other construction applications. RAP is a valuable, high-quality material that can replace more expensive virgin aggregates and binders. The recycling of aggregates and other highway construction materials makes sound economic, environmental, and engineering sense. RAP is a useful alternative to virgin materials because it reduces the use of virgin aggregate required in the construction of roads.

Agencies all around the world adopted the technique of recycling long time ago, while few research studies have been performed to characterize and examine the strength, durability, and suitability of RAP materials in west Africa.



Figure 1.1. Reclaimed Asphalt Materials used in the Study

1.3. Study Objectives

The purpose of this study is to determine the characterizing properties of reclaimed asphalt materials which can provide key knowledge for building sustainable sub base and base pavement layers' infrastructures.

In a general way, this research will be on investigation of geotechnical aspects of reclaimed asphalt materials which include: selection of reclaimed asphalt materials, characterizing the properties, blending the reclaimed asphalt with natural aggregates and examine different RAP/virgin aggregate blending techniques to improve the mechanical characteristics of local RAP materials in Maroua, Cameroon, without the use of chemicals or stabilization additives.

In addition to improve the RAP materials mechanical performance, the investigations will be extended to find the optimum percentage of RAP that can be used as a substitute to virgin aggregate from the economical, and strength point of view. RAP/local virgin aggregate blends technique will be implemented to improve

the mechanical characteristics of local RAP materials. It was intended to conduct a laboratory testing program to achieve these objectives.

1.4. Research Approach

The research will be managed and performed by the Geotechnical Branch of SNER road construction company. The research work will consist of the following tasks: Laboratory testing of virgin material, reclaimed asphalt and blended materials to obtain the values for each of the following test parameters:

- ✓ Gradation
- ✓ Permeability
- ✓ Plasticity Index (PI)
- ✓ Density
- ✓ Unit weight
- ✓ Optimum moisture
- ✓ CBR index

2. LITERATURE REVIEW

2.1. Reclaimed Asphalt Pavement (RAP)

Reclaimed asphalt pavement (RAP) is the term given of removed pavement materials containing asphalt and aggregates (generally well graded crushed stone). These materials are obtained when asphalt pavements are removed for resurfacing, reconstruction or to gain access to buried utilities.

Generally, Asphalt pavement is removed either by milling or full-depth removal. Milling involves the removal of the pavement surface using a milling machine, which can remove up to 2 inch (50 mm) thickness in a single pass. Full-depth removal involves ripping and breaking the pavement using a rhino horn on a bulldozer and/or pneumatic pavement breakers. In most instances, 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. When properly crushed and screened reclaimed asphalt pavement (RAP) consists of high-quality (well-graded aggregates coated by asphalt cement).

Reclaimed asphalt material is the most recycled product in the world, it is being used in various applications. Most of the reclaimed asphalt pavement (RAP) is put back into the roadways as a base, sub base or surface material. RAP is also used in embankment and fill applications throughout the industry.

2.2. Perspective on Using Reclaimed Asphalt Pavement (RAP)

Several agencies are working on the recycling of solid waste on several applications, but highways are among the world's top recyclers. Around 70-80% of asphalt pavement is being reused in the highway application.

Reclaimed asphalt pavement (RAP) is almost always returned back into the roadway structure in some form, usually incorporated into asphalt paving by means

of hot or cold recycling, but it is also sometimes used as an aggregate in base or sub-base construction.

It has been estimated that as much as approximately 33 million metric tons (36 million tons), or 80 to 85% of reclaimed asphalt presently generated, is reportedly being used as a portion of recycled hot mix asphalt, in cold mixes, or as aggregate in granular or stabilized base materials. Some of the RAP that is not recycled or used during the same construction season in which it is generated is stockpiled and is eventually reused.

According to Technical Manual for Design and Construction of Road Tunnels (Civil Elements), the majority of RAP is used in construction and maintenance applications, including:

- ✓ Shoulder surfacing and widening
- ✓ Full-depth reclamation
- ✓ Hot in-place recycling
- ✓ Road base aggregate
- ✓ Cold in-place recycling
- ✓ Various maintenance uses.

According to industry experts, the asphalt pavement industry is the nation's leader in recycling. Each year, 73 million tons of reclaimed asphalt pavements are reused. That is almost twice as much as paper, glass, plastic, and aluminum combined, which is saving taxpayers almost \$300 million annually. The volume of recycled asphalt pavement is 13 times greater than recycling of newsprint, 27 times greater than recycling of glass bottles, 89 times greater than recycling of aluminum cans, and 267 times greater than recycling of plastic containers. Recycled asphalt is used not only for new roads, but also for roadbeds, shoulders and embankments (AASHTO, Center for Environmental Excellence).

Asphalt pavement recycling has many advantages, including:

- ✓ Preservation of existing pavement geometrics
- ✓ Reduced cost of construction
- ✓ Conservation of energy
- ✓ Preservation of the environment
- ✓ Conservation of aggregate and binders.

The use of hot-mix, hot in-place and cold in-place recycling achieves material and construction savings of up to 40, 50 and 67%, respectively. In addition, significant user-cost savings are realized due to reduced interruption in traffic flow when compared with conventional rehabilitation techniques. In the transportation field, recycling asphalt is a win-win proposition, reclaimed asphalt saves the taxpayers' dollars while maintaining high quality in the roadways. Recycling asphalt pavements also shows a healthy respect to the valuable materials used in asphalt pavements.

2.3. Investigation on Reclaimed Asphalt Pavement (RAP)

Several geotechnical branches around the world have conducted a research on the reuse of reclaimed asphalt pavement (RAP) in road construction. The aim of the majority research is based on the physical and mechanical study of the reclaimed asphalt materials and also on the blending reclaimed asphalt with the virgin local materials in the aim to improve the geotechnical properties of reclaimed asphalt material.

2.3.1. Evaluation of the Suitability of Recycled Asphalt Pavement

Kamel M. A.1, Al-Bustami N. M.2, AlSulami B. T.3 (2016) have conducted research on the evaluation of the Suitability of Recycled Asphalt Pavement. The

causes which have led them to make the investigations are the same almost in all the other researches.

The shortage of natural aggregate supplies along with the increase in processing cost has encouraged the use of various reclaimed materials from old structures as a source of construction material. This technology reduces both the cost of highway construction and protects the environment by reducing construction waste. RAP materials have been used as aggregate in the cold recycling of asphalt paving mixtures either by the method of cold mix plant recycling or cold in place recycling process.

These materials are processed using a technique slightly different than that used for new aggregates, but the finished product is usually requested to meet all standard material specification requirements. Some of the engineering properties of reclaimed asphalt pavement (RAP) that are of importance when used in cold recycled applications include its gradation, asphalt content, and the penetration and viscosity of the asphalt binder. The Kingdom of Saudi Arabia has an extensive asphalt roads network of length reached up to 80 thousand kilometers. As the infrastructure ages, these highways and roads must be maintained and rehabilitated so, it is estimated that millions of tons of hot mix asphalt are milled each year. As a result of this practice, a tremendous amount of RAP materials is created every year. Unfortunately, RAP materials are still rarely used in roads construction in KSA. Therefore, it is important to investigate the suitability of using these materials for construction of roads.

Details on used materials on these research

A natural subgrade soil was selected and routine tests were conducted as given below:

- Plasticity limit (ASTM D 4318)

- Liquid Limit (ASTM D 4318)
- Moisture Density relationship (ASTM 698 & ASTM D 1557)
- Gradation (ASTM D 422)

Also, RAP materials were collected and various routine tests conducted on the procured RAP materials as reported below:

- Extraction (ASTM D 2172)
- Moisture Density relationship (ASTM 698 & ASTM D 1557)
- Gradation (ASTM D 422)

Moreover, variable RAP percentages were selected viz., 0, 10, 50, 90 and 100 % and mixed with the investigated natural subgrade soil in order to check the suitability of this mix in roads construction.

Details on conducted routine tests in these research

A set of tests were conducted to reveal some judgment factors that can be used to optimize the RAP ratio in the RAP/soil mixtures. These tests include Compaction, California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS)

1. Compaction Test

Modified Proctor Compaction test (ASTM D698) was performed on all selected materials to determine the relationship between the moisture content and the dry density for a specified compactive effort.

2. California Bearing Ration Test (CBR)

CBR tests were conducted as per ASTM D1883 (ASTM 1999) on the selected materials in order to check the suitability of these materials for subbase course in pavement systems.

3. Unconfined Compressive Strength Test (UCS)

The loads applied to a pavement in service are transient and it is doubtful whether any drainage takes place during the loading cycle therefore, unconfined compressive strength test was conducted as per ASTM D2850 (ASTM 2003) on all selected materials to study their stress-strain behavior and to determine the modulus of elasticity (E-value) as an indicator of the material strength and subsequently, its suitability for roads construction. E-value was considered as the initial tangent of the stress-strain curve. For this concern, cylindrical specimens of size 100 mm diameter and 200 mm height were prepared. The water corresponding to the optimum moisture content (OMC) was added and mixed thoroughly. Care was taken during the compaction procedure to ensure that the sample is uniform throughout its height, with little or no variation in density. The dry density of the samples was checked and was within a range of $\pm 3\%$ of the maximum dry density obtained through Proctor's test.

The conclusion that researchers Kamel M. A.1, Al-Bustami N. M.2, AlSulami B. T.3 (2016) have issued at the end are below:

The main findings of the present investigation can be summarized as follows:

- RAP can be used to improve subgrade layer.
- Blending with natural soil up to 50%, can be used as Sub-Base material.
- The more RAP ratios, the less OMC, E-values and ultimate stress
- Failure strain did not gain a definite trend with the variation of RAP ratio

2.3.2. Improvement of the Mechanical Characteristics of Reclaimed Asphalt Pavement

Department of Highways & Transp., College of Engineering, Al Mustansiriyah University. Saud A Sultan¹, Mohammed B Abduljabar¹ and Mariam H Abbas¹(2013) have conducted research on "Improvement of the mechanical characteristics of reclaimed asphalt pavement". The procedures of this research are similar to the previous search. The objective of this study was to investigate and examine different RAP/virgin aggregate blending techniques to improve the physical and mechanical characteristics of local RAP materials in Iraq's. In addition to improve the RAP materials mechanical performance, the investigations will be extended to find the optimum percentage of RAP that can be used as a substitute to virgin aggregate from the environmental, economical, and strength point of view. RAP/ local virgin aggregate blends technique will be implemented to improve the mechanical characteristics of local RAP materials in Iraq. It was intended to conduct a laboratory testing program to achieve these objectives.

A laboratory testing program was conducted on reclaimed asphalt pavement (RAP) using different blending techniques to study and to improve their mechanical properties. The testing program is devoted to test the reclaimed asphalt materials characteristics in the first place and then testing of mixes that contain different proportions of RAP in addition to local available virgin aggregate materials that are used in road construction. The purpose of this research was to investigate the effect of RAP content on the mechanical properties of base and subbase materials. Different RAP contents and three different local virgin base and subbase materials were studied. Three replicate samples of each possible combination were tested.

The laboratory tests allowed the researchers Saud A Sultan¹, Mohammed B Abduljabar¹ and Mariam H Abbas¹(2013) to conclude that:
Effects of blending local virgin Subbase materials with RAP materials

There are important economical and environmental benefits of reducing the quantity of local virgin subbase materials used in road construction by up to 40% due to the addition of useless RAP materials.

Effects of blending local natural gravel with RAP materials

There are important economical and environmental benefits of reducing the quantity of local natural gravel materials used in road construction by up to 60% due to the addition of useless RAP materials.

Effects of blending local crushed aggregate with RAP.

There are important economical and environmental benefits of reducing the quantity of local crushed aggregate materials used in road construction by up to 40% due to the addition of useless RAP materials.

Life cycle cost analysis

The computerized design and management analysis, which was carried out on life cycle costs of flexible pavement with unbounded granular subbase layer of blended virgin aggregate materials with RAP showed savings of up to 39% of total pavement cost depending on design in comparison with conventional flexible pavement in Iraq.

2.3.3. Developing Specifications for Using Recycled Asphalt Pavement as Base, Subbase or General Fill Materials

P.J. Cosentino, E. H. Kalajian, C. S. Shieh, W. J. K. Mathurin, F. A. Gomez, E. D. Cleary, and A. Treeratrakoon, Florida Institute of Technology uses a stiffness strength value of Limerock Bearing Ratio (LBR) that is similar to a California Bearing Ratio. Previous laboratory testing research reports were compared. This research report did a field test deck. RAP and blends of RAP and soil mixtures were tested. A series of tests were performed, including gradations, moisture densities, temperature profiles, FWD using MODULUS 5.1 program to process data, permeability, etc. The resilient modulus decreased with the addition of material

passing the 40 sieve. The study recommended that a long-term strength deformation (creep or large strain) behavior of RAP and RAP-soil mixes should be investigated.

2.3.4. The Development of a Performance Specification for Granular Base and Subbase Material

Maher, Ali, and Bennert, Thomas, Department of Civil and Environmental Engineering, Center for Advanced Infrastructure & Transportation, Rutgers, The State University, Piscataway. This research project encompassed evaluating the performance of New Jersey DOT specified aggregates at the respective New Jersey DOT gradation ranges (high end, middle, and low end) and provided guidance as how to modify the gradation ranges to provide better performance.

Base and subbase materials were sampled from three regions in that state and evaluated under the following performance tests: permeability (falling and constant head conditions), triaxial shear strength, cyclic triaxial loading, California Bearing Ratio (CBR) and resilient modulus. Testing was also conducted on reclaimed asphalt pavement (RAP) and reclaimed concrete aggregate (RCA) to evaluate their potential use as base and subbase materials. The testing of the RAP, RCA, and their blends with the base material, showed that as the % RAP increased in the blend, both the CBR value and permeability decreased. RAP also caused larger permanent deformations during the cyclic triaxial testing.

2.3.5. The Interests Derive from This Relevant Researches

This research allowed us to find response and procedures adapted during our investigations. In a general way all the research I could read during my investigation gives the same conclusions.

These researches are made in other countries and other continents but in western Africa the data on the reuse of solid waste is very rare.



3. MATERIALS AND TEST PROCEDURE**3.1. General Information on Road Aggregates****3.1.1.. Definitions**

The French standard (French Association of normalization, AFNOR) defines aggregate as a set of mineral grains, with dimensions between 0 and 80 mm, intended for the preparation of mortars and concretes as well as base and subbase layers of pavements.

3.1.2. Road Materials Properties

The geotechnical characteristics of the materials used in road construction generally are: the granularity, the compactness and the bearing capacity.

- The granularity

It characterizes dimensional distribution of the aggregate. The granularity is important because it makes it possible to obtain maximum compactness and to avoid segregation at the time of implementation.

- Compactness

Compacting a material means reducing the void volume of this material and organizing the grain structure to achieve a more stable assembly. This operation, called compaction, can be achieved by static (static compaction), dynamic (dynamic compaction), or vibration (in situ compaction).

The compaction effect on the lifetime of structures: The compacting gives the material a sufficiently tight state, so materials settlement is impossible or minor. Relative movements are reduced or eliminated, thus decreasing attrition. By reducing void volume, compaction increases the dry bulk density and decreases the permeability which is a function of the void index.

The influential parameters of compaction are:

- The water content
 - The nature of the material
 - Compaction energy
 - Angularity, shape, granularity and percentage of fines
-
- Bearing capacity

It is based on the resistance to punching of the foundation soil, which is evaluated by a standardized CBR test, and on the Boussinesq theory giving the depth distribution of the vertical pressures (Fall, M., 1993).

3.1.3. Pavement Structures

The ground alone can't withstand road traffic without undergoing significant deformation. This is why it is surmounted by a corps of roadway whose main role is the lateral distribution of the stresses due to rolling loads on the surface in order to bring them to levels compatible with the mechanical characteristics of the natural soil.

Pavement design influential parameters:

- A traffic solicitation: T1: Very light; T2: light; T3: medium; T4: Heavy; T5: very heavy; T6: extremely heavy.
- The bearing class (S0, S1, S2, S3, S4) can be determined by the Me1 module, the Ev1 module, the CBR coefficient, and the Westewald reaction module k.
- Gelivity: the degrees of soil gelling are determined by the classes (G1, G2) for low gelling soils and (G3, G4) for gelling soils but gelivity parameter is not used in tropical country.

3.1.3.1. Types of Pavements

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance. Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements. Our investigation is focused on flexible pavement.

Flexible pavements: In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The flexible pavement, having less flexural strength.

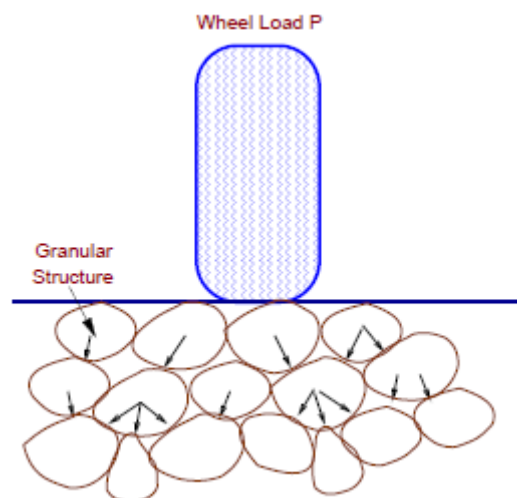


Figure 3.1. Load transfer in granular structure

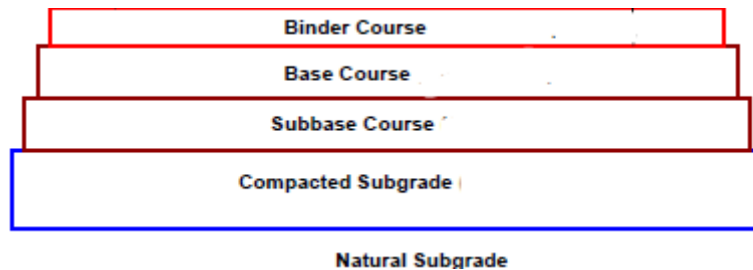


Figure 3.2. Typical cross section of a flexible pavement

3.1.3.2. Typical layers of a Flexible Pavement

Typical layers of a conventional flexible pavement include binder course, base course, sub-base course, compacted sub-grade, and natural sub-grade.

Binder course

This layer provides the bulk of the asphalt concrete structure. Its chief purpose is to distribute load to the base Course.

Base course

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

Sub-Base course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure.

Sub-grade

The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is

overstressed. It should be compacted to the desirable density, near the optimum moisture content.

3.1.3.3. Requirements of a Pavement

An ideal pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
- Structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed,
- Produce least noise from moving vehicles,
- Dust proof surface so that traffic safety is not impaired by reducing visibility,
- Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost.

3.1.3.4. Structural Calculation Analysis

We have two major methods recognized for road structural calculations,

Rational method: This method uses the structure of the roadway through a mechanical model to determine constraints and deformations.

Empirical method: This method consists of observing the behavior of roadways on traffic condition and deducing from it the practical rules of the road design. For the research we use the California Bearing Ratio method that are include in the Empirical method.

3.1.3.5. California Bearing Ration Calculation Method

it is a semi empirical method which is based on a California bearing ration test to fix the road layer thickness.

The process details are below:

The determination of the total thickness of the pavement layers to be implemented is obtained by applying the following formula:

- For a particular car traffic: Average daily traffic x 365x 1,5t < 100000 t/year

$$e = \frac{100 + 150 \sqrt{P}}{ICBR + 5} \text{ cm}$$

- For a particular car traffic: Average daily traffic x 365x 1,5t >> 100000 t/year

$$e = \frac{100 + \sqrt{P} \times (75 + 50 \log_{10} \frac{N}{10})}{ICBR + 5} \text{ cm}$$

with:

- e = thickness
- Icbr: CBR Index
- N: denotes the daily number of trucks over 1500 kg empty
- P: load by road P = 6.5 t (axle 13 t)
- Log: decimal logarithm

3.2. Used Road Materials**3.2.1. Used Materials**

The laboratory investigations were carried out on 3 types of materials: Reclaimed Asphalt Pavement (RAP) as waste material, Laterite (Virgin local aggregate generally used in road subbase layers), crushed stone 0-31,5 (whole coming aggregate used in road base layers).

3.2.2. Reclaimed Asphalt Pavement (RAP)

RAP is the removed or reprocessed asphalt materials and aggregates for pavement reconstruction. Full-depth reclamation uses a mix of the base material and the deteriorated asphalt pavement with virgin aggregate to create a new stabilized base material. The asphalt used in this study is from an old road built in 1970, the hot climate of the area began to cause cracks in the asphalt that constitutes the road's top layer and the rehabilitation of this layer is necessary.

The asphalt aggregates that come from this layer are a good material for our research because the majority of asphalt waste comes from the same conditions of degradation in West Africa. To obtain a representative sample, the sampling was carried out at 4 points distant of 2km each on the road.

Reclaimed asphalt pavement is mostly aggregate material and is itself granular and can be used in a variety of applications for which freshly produced natural aggregates have traditionally been used. Highway agencies often require that reclaimed materials satisfy most of the virgin aggregate specifications, with certain tests often relaxed, especially when they are irrelevant or inappropriate for the particular recycled material under consideration.

With regard to reclaimed asphalt (RAP) intended for use as granular material in base and subbase applications, key factors for good performance are grading, particle toughness as measured by the plasticity of fines. Soundness of individual particles could be of concern or discounted depending on the particular original aggregate component of the asphalt and if necessary can be assessed by unconfined freezing and thawing. Performance-related parameters to be assessed for the granular mixture include the moisture density relationship, permanent deformation (repeated load triaxial testing), and frost susceptibility (tube suction). These assessments of the bulk mixture together with the descriptive and quality tests provide up to- date methods for evaluating and selecting materials for use as granular base and subbase.



Figure 3.3. Selected Reclaimed Asphalt Materials (RAP)

Table 3.1. Typical Properties of reclaimed asphalt

S. No	Parameters	Values
1	Unit Weight (Kg/m^3)	1900- 2250
2	Moisture Content Max	3- 5%
3	Asphalt Content	5- 6%
4	Asphalt Penetration(%) at 25°C	10-80
5	Compacted Unit Weight	1500- 1950
6	Bearing Ratio (CBR) 100% RAP	20-25%

3.2.3. Laterite

A lateritic soil is a residual soil of tropical alteration, constituted of a mixture of particles generally between 2 and 20 mm (pisoliths, concretions or more or less hard nodules and / or quartz kidneys) and lateritic clay of Color most often reddish or ocher (sometimes gray). The granularity of the mixture is quite often

discontinuous, marked by a characteristic absence of sandy elements with dimensions of between 0.2 and 2 mm.



Figure 3.4. Laterite material sample.

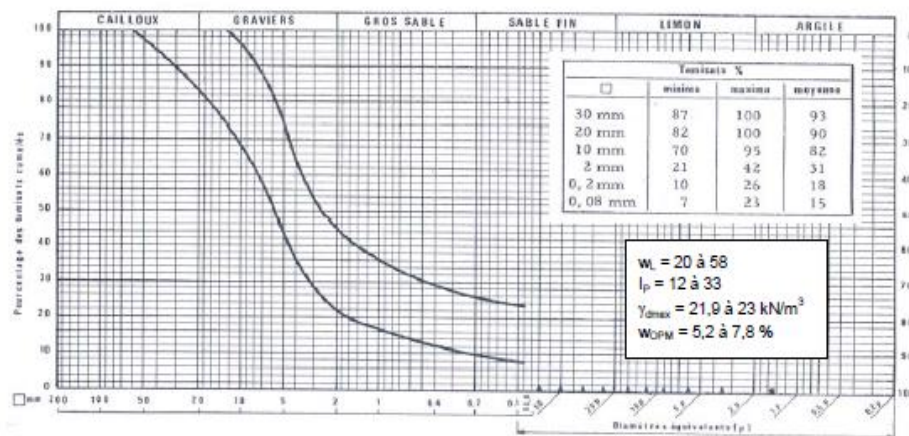


Figure 3.5. Example of size particle distribution curve envelope of lateritic soil (Afnor classification).

Geotechnical classification of lateritic soil

As early as 1967, three lateritic soil classes had been identified (Table 3.2), Corresponding to decreasing geotechnical qualities (G1, G2, G3). The Successive classifications have resulted in refining the distinctions, but the three classes are subdivided.

Table 3.2. Lateritic properties

Category	Plasticity index	Content of fines particles %	Mean values of geotechnical characteristics		
			ICBR 95% 4 day imbibed	Max dry Density	Moisture content
G1	5-15	5-15	30 to 80	2,10-2,30	5-8%
G2	15-25	15-25	20 to 50	2,0-2,25	9-10%
G3	25-35	25-35	15 to 40	1,90-2,20	8-12%

According to the international classification systems, lateritic soil to the GP (Poorly Graded Soil), GM (soil LCPC classification) or to A-2-6 or A-2-7 soils (HRB classification), the plasticity and the proportion of the fines in the lateritic soil are very high, in which case they may correspond according to the American classification to (soils A76).

3.2.4. Crushed Stone 0-31,5, Used for Road Base Layers

The whole coming: mixture of aggregates of all dimensions, used in road construction for the realization of the base layers and for foundations serving as base for the concrete pavements.



Figure 3.6. Crushed stone 0/31,5 mixture of aggregates

3.2.4. Laboratory Tests

The laboratory works program is devoted to the first place to use common types of soil tests for road construction to test the reclaimed asphalt materials characteristics then testing of mixes that contain different proportions of reclaimed asphalt in addition to local available virgin aggregate materials that are used in road construction. The purpose of this research is to adapt the physical and mechanical properties of reclaimed asphalt to that of virgin materials used in the subbase and base layers in road construction.

The different tests were carried out in this research according to the Afnor standards are:

Particle size distribution - NF P 94 – 056

This is done to determine the waste soil gradation. Coarser particles are separated in the sieve analysis portion, and the finer particles are analyzed with a hydrometer. The distinction between coarse and fine particles is usually made at 75

µm. The sieve analysis shakes the sample through progressively smaller meshes to determine its gradation. The hydrometer analysis uses the rate of sedimentation to determine particle gradation.

Atterberg limit (W L) – NF P 94 – 051

The Atterberg limits define the boundaries of several states of consistency for plastic soils (waste material). The boundaries are defined by the amount of water a soil needs to be at one of those boundaries. The boundaries are called the plastic limit and the liquid limit, and the difference between them is called the plasticity index. The shrinkage limit is also a part of the Atterberg limits. The results of this test can be used to help predict other engineering properties.

Modified Proctor Compaction test NF P 94 - 093

Compaction test was performed on all selected materials to determine the relationship between the moisture content and the dry density for a specified compactive effort.

C B R (California bearing ratio) Immerse at 4 day - NF P 94 – 078

A test to determine the aptitude of the waste material or aggregate sample as a road subgrade. A plunger is pushed into a compacted sample, and its resistance is measured. This test was developed by Caltrans, but it is no longer used in the Caltrans pavement design method. It is still used as a cheap method to estimate the resilient modulus.

4. INVESTIGATION OF RECLAIMED ASPHALT AS A ROAD SUB BASE MATERIAL

Hamadou Lamido SALIFOU

4. INVESTIGATION OF RECLAIMED ASPHALT AS A ROAD SUB BASE MATERIAL

4.1. Research Method

Before testing the Reclaimed Asphalt, it is essential to make a complete identification of the virgin materials (laterite) used in the road subbase layer to have the exact values which will constitute a reference to compare the values of reclaimed asphalt.

The research will be carried out in two stages for each test: the first step is testing the laterite to determine the properties and the second step we will test the reclaimed Asphalt.

4.2. Particle Size Distribution Test of Lateritic Soil - NF P 94 – 056

In these test we have to find the particle size curves envelope of lateritic (virgin local aggregate) in order to have the minimum and the maximum curves where the reclaimed asphalt curve will be adapted. To find the envelope of these curves several steps are necessary.

Laterite sample collection

To find the curves envelope several samples of laterite must be taken at different points (see details of sampling), make the particle size analysis for each sample and on a representative sample(the mixes of samples) of all these different points, this will allow us to have the minimum and the maximum of the particle size curve, also the results of the complete identification of the representative sample will be a reference to judge the results of the tests that we will have to do on the RAP materials.

4. INVESTIGATION OF RECLAIMED ASPHALT AS A ROAD SUB BASE MATERIAL

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Lateritic soil samples collection plan: PK 18+250/D

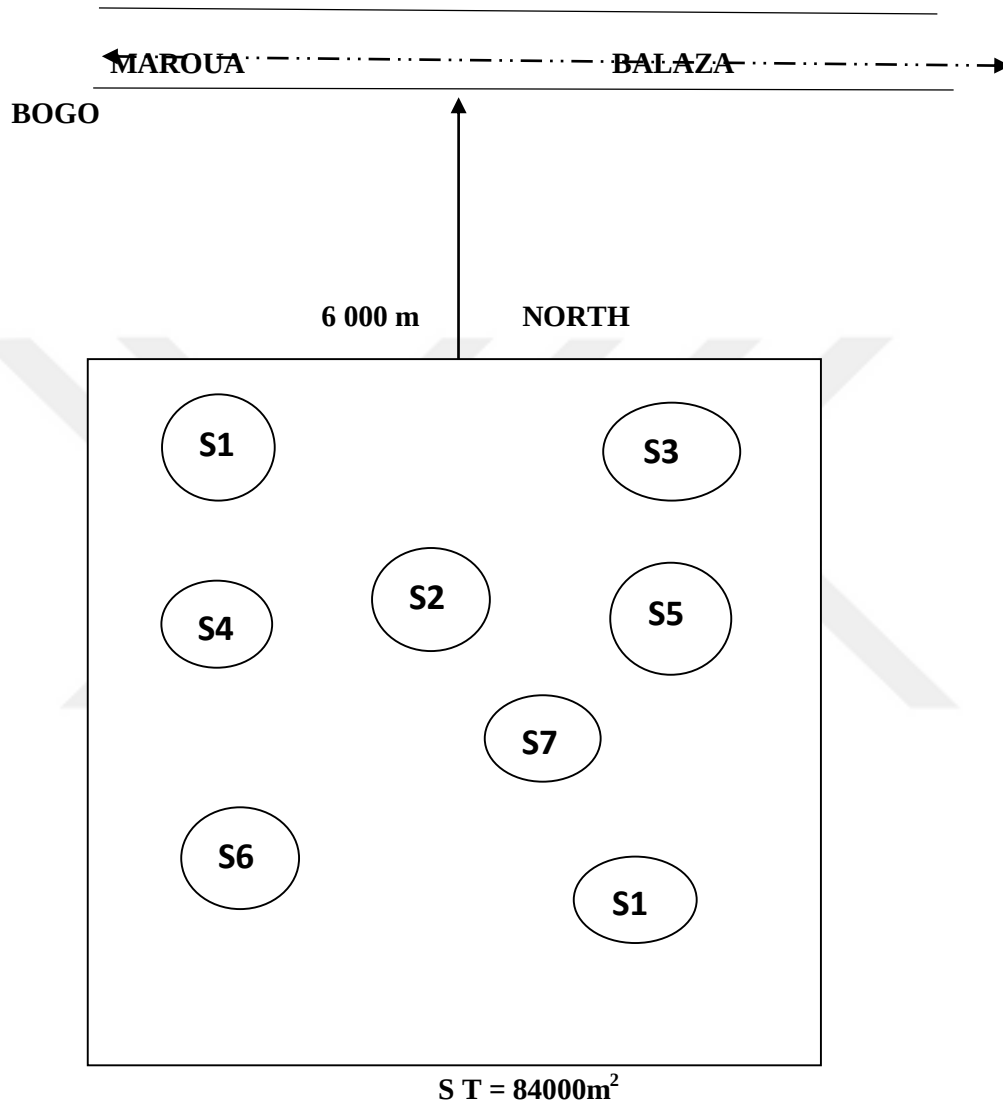


Figure 4.1. Lateritic soil collection plan.

4. INVESTIGATION OF RECLAIMED ASPHALT AS A ROAD SUB BASE MATERIAL

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Table 4.1. Details of lateritic soil layers in the sampling area

N° Reception	SONDAGE	Landmarks	DEPTH	Type of soil
		PK, BORNE OU AUTRE		
0017	S1	PK	00 - 40cm 40 - 200 cm	Topsoil Laterite
0018	S2		00 - 25 cm 25 - 180 cm	Topsoil Laterite
0019	S3		00 - 30 cm 30 - 190 cm	Topsoil Grave Lateritic
0020	S4		00 - 40 cm 40 - 200cm	Topsoil Grave Lateritic
0024	S5		00 - 30 cm 30 - 190 cm	Topsoil Grave Lateritic
0023	S6	18+250/D	00 - 30 cm 30 - 200 cm	Topsoil Grave Lateritic
0021	S7		00 - 30 cm 30 - 200 cm	Topsoil Laterite
0022	S8		00 - 40 cm 40 - 180 cm	Topsoil Laterite

4.2.1. Particles Size Test Result

For the particle size test, we used the sieving method. The sieve analysis is carried out to determine the distribution of the particles according to their size, in the table below there is the particles distribution of 8 samples. The table will allow us to plot the particle size curves of each sample.

4. INVESTIGATION OF RECLAIMED ASPHALT AS A ROAD SUB BASE MATERIAL

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Table 4.2. Particle size distribution of lateritic soil S1 to S8

Sieve (mm)	S1 passing	S2 passing	S3 passing	S4 passing	S5 passing	S6 passing	S7 passing	S8 pass
25			100					
20			98,5	100	100			
16	100	100	97,5	99,5	98,7	100	100	100
12,5	99,4	97	95,4	98,8	98,3	97,9	99,8	99,6
10	97,8	94,7	93,8	97,4	97,2	94,9	99,4	97,4
8	95,2	91,8	91,5	94,8	95,6	90	98,6	94,8
6,3	91,6	88,4	89,5	91,5	93,5	84,2	97,3	91,9
5	86,7	83,1	86,8	86,2	90,1	77,7	94,1	88,3
2,5	61,8	58,1	68,4	63	65,7	53,7	65,7	62,6
2	53,5	52,4	60,3	54,9	59	47,5	59	56,9
1,25	42,4	45,5	51	43,1	51,1	39,6	51,8	50,8
1	38,2	43	47,9	38,7	48,4	36,7	49,3	48,6
0,63	33,3	39,7	44,1	33,3	44,7	33,2	46,1	46
0,5	31,6	38,6	42,8	31,4	43,5	32	45	45
0,4	30,5	37,6	41,8	30	42,6	31,1	44,1	44,3
0,25	28,3	35,8	39,8	27,7	40,6	29,4	42,7	42,9
0,2	27,4	34,7	38,6	26,5	39,6	28,5	41,1	41,9
0,16	26,2	33,2	37,2	25,3	38,3	27,4	39,8	40,9
0,125	24,9	31	34,8	23,7	36,3	26,1	37,9	39
0,1	23,6	29	32,4	22,2	34,5	24,5	35,9	37,2
0,08	21,1	26,7	30,1	20,4	32	22	34	34,6

4. INVESTIGATION OF RECLAIMED ASPHALT AS A ROAD SUB BASE MATERIAL

Hamadou Lamido SALIFOU

4.2.2. The Particle Size Distribution Graphic of Laterite

Plotting the curves of the 8 samples in the same table allows us to have the minimum curve and the maximum curve. The minimum and maximum curves allow us to have the particle size distribution curves envelope which will serve to adapt the curve of the reclaimed asphalt.

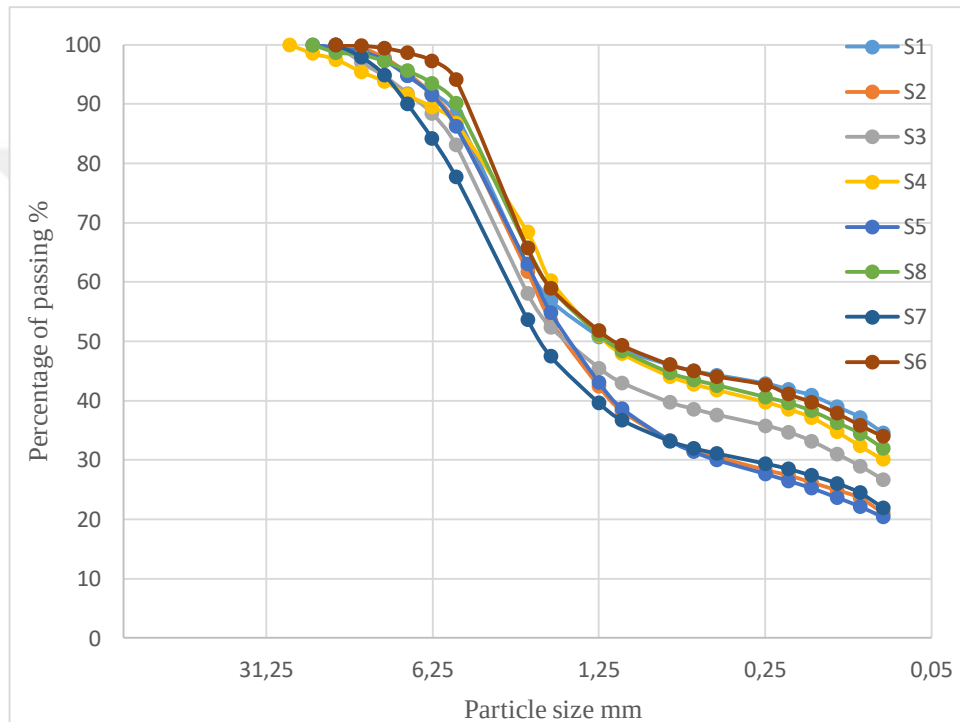


Figure 4.2. The particle size distribution graphic of lateritic soil S1 to S8

In the table, we see that the graphs S6 and S7 constitute respectively the minimum and the maximum of the different materials, it can therefore be deduced that the space between the curves S6 and S7 is the envelope where all the curves of the materials to be used in the sub-base layer of a road will be adapted.

4. INVESTIGATION OF RECLAIMED ASPHALT AS A ROAD SUB BASE MATERIAL

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➤ Representative Sample Graphic

In the graph below we plot the curve of the representative sample of all seven (7) lateritic soil samples with the envelope curves which are the maximum and the minimum.

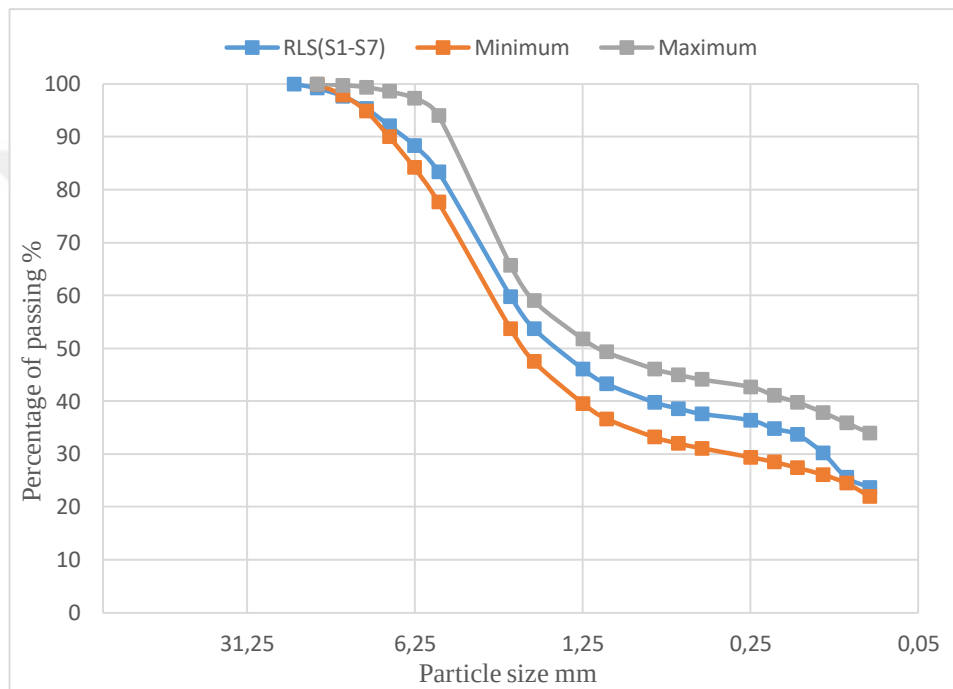


Figure 4.3. The particle size distribution graphic of representative sample between S1 to S7

As the graph shows, the representation of the sample gives a particle size that passes between the minimum and the maximum curves. Therefore, the sample is a good material for road subbase. the results of the analyzes of this sample constitute for us a good reference for the continuation of our research.

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4.3. Particle Size Distribution Test of Reclaimed Asphalt Material - NF P 94 056

Particle size test of reclaimed asphalt will allow us to have the particle size curve which will be compared to that of the laterite. The table below contains the particle size distribution of the reclaimed asphalt.



Figure 4.4. Reclaimed asphalt material Particle size test.

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Table 4.3. The particle size distribution of tested reclaimed asphalt material.

Sieve (mm)	Modules	Mass cumul (g)	% retained	% passing
20	44	0	0	100
16	43	215,6	2,9	97,1
12,5	42	940,7	12,8	87,2
10	41	2073,7	28,1	71,9
8	40	3380,8	45,8	54,2
5	38	5036,7	68,3	31,7
4	37	5550,0	75,3	24,7
2	34	6391,5	86,7	13,3
1	31	6841,9	92,8	7,2
0,63	29	7010,1	95,1	4,9
0,4	27	7124,9	96,6	3,4
0,16	23	7268,4	98,6	1,4
0,080	20	7333,1	99,4	0,6

4.3.1. Reclaimed Asphalt Particle Size Distribution Graphic

We plot the reclaimed asphalt curve in the preceding table containing the curve envelope of the laterite and the curve of the representative sample. This will enable us to appreciate the curve of the reclaimed asphalt.

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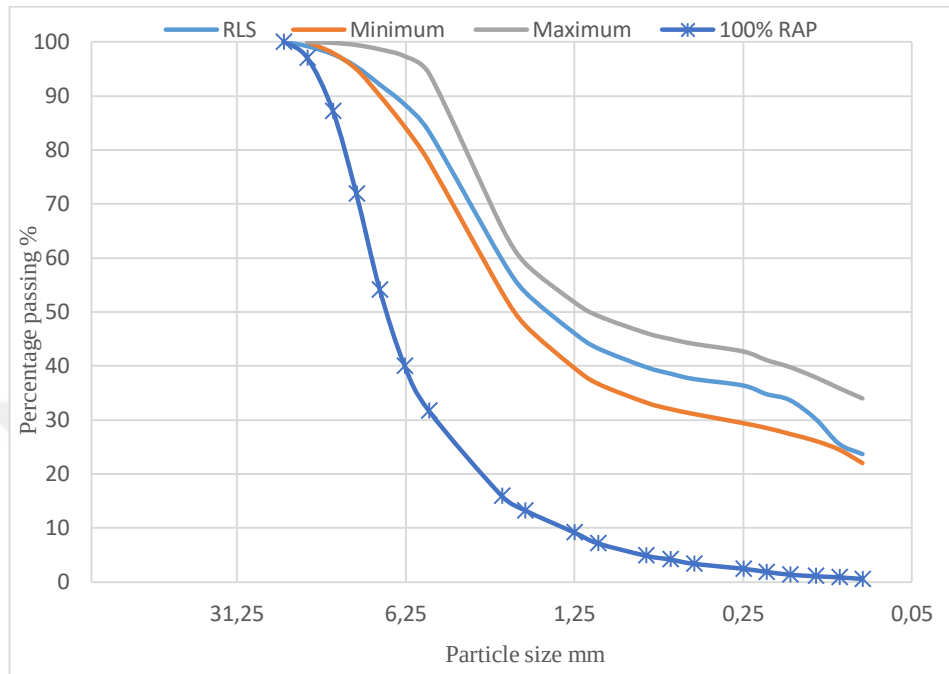


Figure 4.5. The particle size distribution curve of tested RAP material.

The result of the particle size test shows that the graph of the RAP material does not pass between the minimum and maximum curves, it can be concluded that the RAP material cannot be used as a road sub base material. A modification of particles distribution is needed to adapt the curve of the reclaimed asphalt to that of the laterite.

4.4. Amelioration of Reclaimed Asphalt Materials by Blending with Local Virgin Material (lateritic soil)

In order to reuse the reclaimed asphalt material in the road construction, a particle size improvement of this material is required. We will try to improve the reclaimed asphalt material by blending it with the virgin material of the laterite (RLS).

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4.4.1. Blending Method

The improvement of reclaimed asphalt particles distribution consists of blending the reclaimed asphalt with RSL (representative sample of the laterite). This makes the possibility to bring the size of the reclaimed asphalt to the required size and the appropriate classification required for the sub-base according to the specifications NF P 94 – 056.

Samples of different compositions were prepared by adding different percentage of RAP materials (50% RAP, 40%RAP, 30%RAP).



Figure 4.6. Blended lateritic soil with reclaimed material.

4.2.2. Blending Materials Particles Sieving Result

Samples of different compositions were prepared by adding different percentage of reclaimed asphalt materials (50% RAP, 40%RAP, 30%RAP).

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Details of samples blending:

Asphalt + laterite (representative sample) = 5 kg

✓ **100% RAP (reclaimed asphalt)**

RAP = 5 kg See the results in the preceding table

✓ **50% RAP**

Blending of 2.5 kg of RAP + 2.5 kg of RLS

✓ **40% RAP**

Blending of 2 kg RAP + 3 kg of RLS

✓ **30% RAP**

Blending of 1,5 kg of RAP + 3,5 kg of RLS

Particles size test result in the table below

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Table 4.4. The particle size distribution of blended RAP material

Sieve (mm)	100% RAP	50% RAP	40%RAP	30% RAP	0% RAP
25		100	100	100	
20	100	99,6	99,5	99,7	100
16	97,1	96,5	97,9	98,5	99,2
12,5	87,2	87,6	92,8	96	97,7
10	71,9	76,4	86,8	93,4	95,4
8	54,2	63,8	78	88,7	92,1
5	31,7	45,5	62,8	79,8	83,4
4	24,7	36,9	57,2	68,2	75,1
2	13,3	18,8	35,1	51,3	53,7
1	7,2	10,4	25,2	40,4	43,3
0,63	4,9	7,3	21,7	36,3	39,8
0,4	3,4	5,7	19,4	35,5	37,6
0,16	1,4	2,6	16,1	31	33,7
0,1	0,6	1,3	14,2	24,6	25,6
0,08	30,5	0,3	13,4	22,6	23,7

4.4.2. Blending Materials Graphics Analysis

All graphics was plotted successively in the preceding table containing the curve envelope of the lateritic soil and the curve of the representative sample. This will enable us to appreciate the blended material curve evolution.

▪ 100% RAP (reclaimed asphalt)

RAP = 5 kg See the results in the preceding table

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▪ 50% RAP

Blending of 2.5 kg of RAP + 2.5 kg of laterite

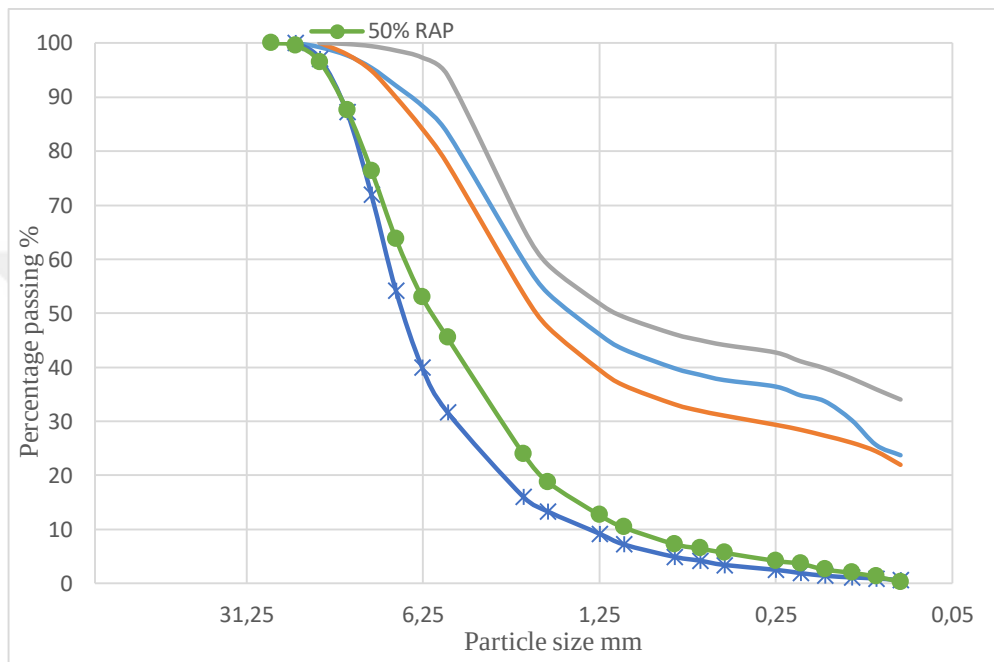


Figure 4.7. The particle size distribution curve of 50% RAP material.

For 50% reclaimed asphalt and 50% laterite we observe a slight improvement of the curve towards the envelope of the curves of the virgin material. This improvement can be estimated at about 5-10%. A supply of virgin material is still necessary.

▪ 40% RAP

Blending of 2 kg RAP + 3 kg of laterite

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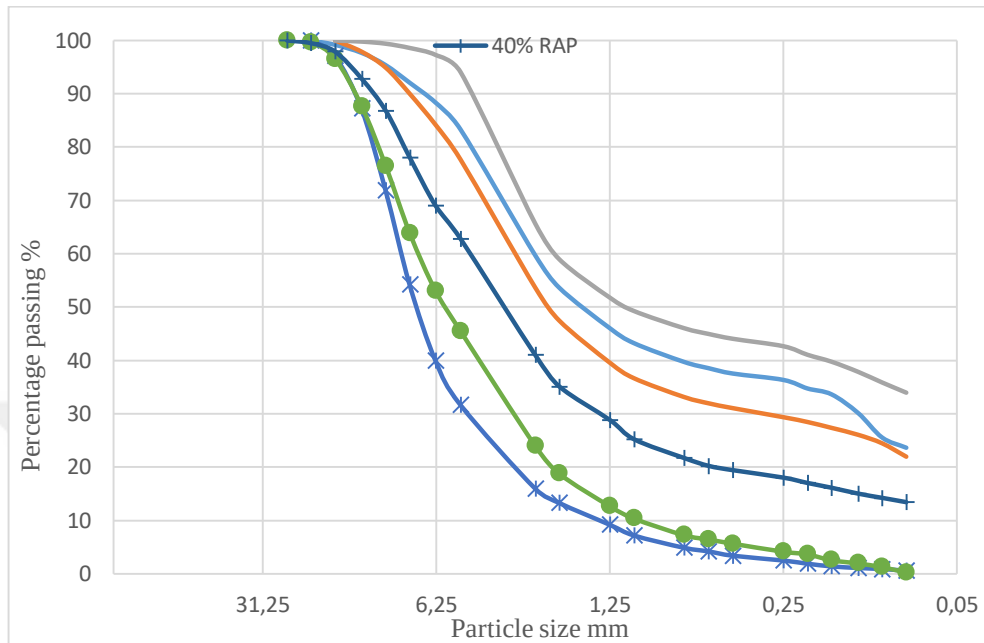


Figure 4.8. The particle size distribution curve of 40% RAP material.

The blending of 40% reclaimed asphalt and 60% laterite give a good improvement of the curve. The percentage increasing of virgin materials led to an evolution of more than 50%.

▪ 30% RAP

Blending of 1,5 kg of RAP + 3,5 kg of laterite

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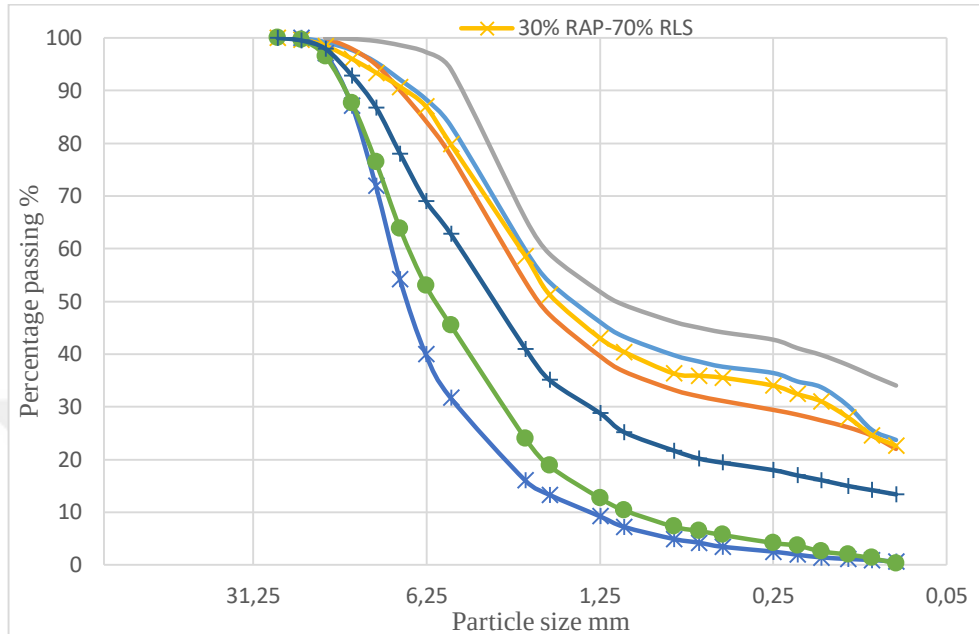


Figure 4.9. The particle size distribution curve of 30% RAP material.

The mixture of 30% reclaimed asphalt and 70% laterite give a curve that enters in the envelope curves which constitutes the tolerance zone and come toward the curve of the representative material. The particle size distribution of this mixture corresponds to the prescribed standard of the laterite intended for the sub base layer.

4.4.3. Particle Size Test Conclusion

The blending of RAP by adding different percentage of virgin materials allows the curve to progress towards the mini and maxi curves. As shown in the graphic table, the mixture of 30% reclaimed asphalt and 70% laterite gives us a curve closest to the curve of the representative sample. The material '30% RAP and 70% lateritic' gives us a curve that has a distribution of particles appropriate to the subbase layer of a road according to standard NF P 94-056, Therefore the material '30% RAP and 70% lateritic' will be our materials on which we will conduct the different tests.

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The tests conducted on the '30% RAP and 70% laterite' will be compare to the different result lead on the representative sample of the laterite.

Table 4.5. The particle size distribution of 30% RAP and 70% laterite

Sieve (mm)	LATERITE%	Sieve (mm)	RAP%
20	100	25	100
16	99,2	20	99,7
12,5	97,7	16	98,5
10	95,4	12,5	96
8	92,1	10	93,4
6,3	88,4	8	90,7
5	83,4	5	79,8
2,5	59,8	4	72,2
2	53,7	2	51,3
1,25	46,1	1	40,4
1	43,3	0,63	36,3
0,63	39,8	0,4	35,5
0,5	38,6	0,16	31
0,4	37,6	0,1	24,6
0,25	36,4	0,08	22,6
0,2	34,8		
0,16	33,7		
0,125	30,2		
0,1	25,6		
0,08	23,7		

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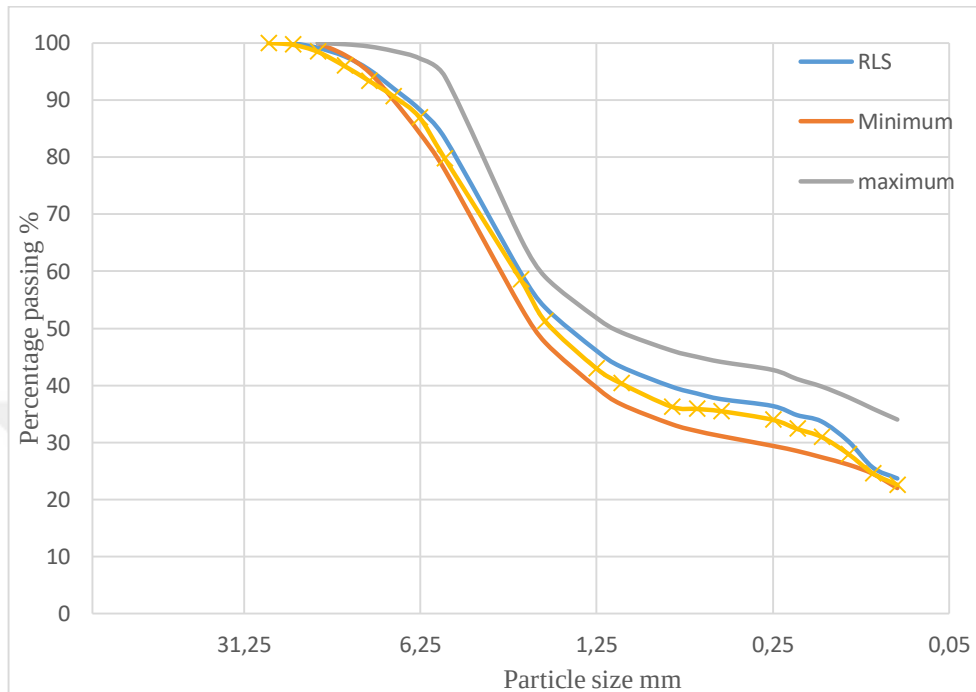


Figure 4.10. The particle size distribution graphic of RLS'30% RAP and 70% laterite'.

4.5. Atterberg Limit (w_L) – NF P 94 – 051

The purpose of these tests is to determine the consistency limits that are expressed in terms of water content marking the boundaries between solid state, plastic, and liquid. It is important to note that these tests apply only to fine soils, defined as grains with diameters less than 0.08 mm.

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Figure 4.11. Laboratory work Atterberg limit.

4.5.1. RLS (Representative Sample of Laterite) Atterberg Limit Test

The test of atterberg limit on the RLS (Representative sample of laterite) gives us the following results:

WL	WP	IP
27,8	20,3	7,5

4.5.2. Blended Material (30 %RAP and 70% RLS) Atterberg Limit Test

The test of atterberg limit on the Blended material (30 %RAP and 70% RLS) gives us the following results:

WL	WP	IP
25,1	19,2	5,9

4.5.3. Atterberg Limit Test Conclusion

The plasticity index $I_p = WL - WP$ allows us to characterize the clay content of a soil. According to the GTR classification $0 < IP < 12$ low clay content. According to this classification the two materials contain little clay and are in the same class.

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4.6. Modified Proctor Compaction test NF P 94 – 093

Modified Proctor Compaction test (NF P 94 - 093) was performed on representative laterite sample and selected 30% reclaimed asphalt 70% RLS materials to determine the relationship between the moisture content and the dry density for a specified compactive effort.



Figure 4.12. Picture of laboratory work Proctor test.

4.6.1. RLS (Representative sample of laterite) Proctor Test

Plot the moisture content versus dry density on graph paper with the vertical side representing dry density in kg/m^3 and the horizontal side representing moisture content in percentages. To have the maximum dry density and the moisture content of RLS three proctor tests are necessary (see the result in the table).

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Table 4.6. CBR results of tested lateritic soil (virgin material)

Modified proctor				
Proct.n°	1	2	3	Val.opt
Mosture W %	4,6	6,9	10,5	7,30
Dry density δ_d KN/m ³	19,4	21,0	20,3	21,03

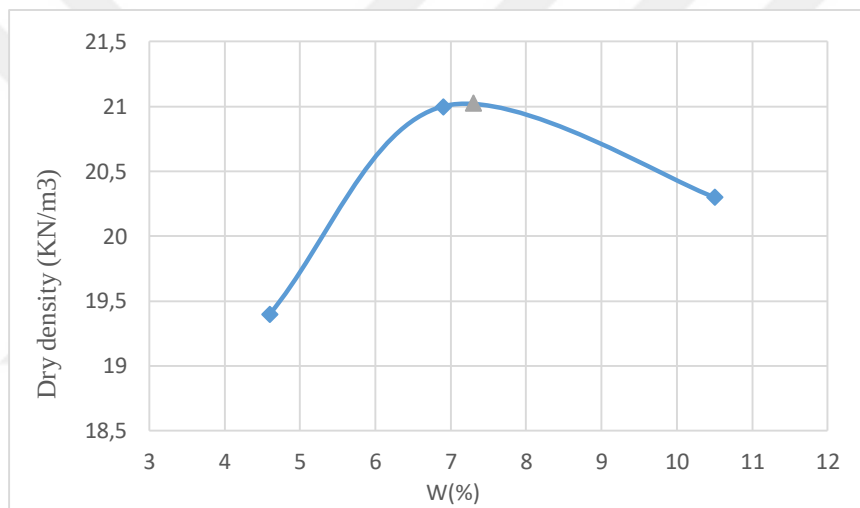


Figure 4. 13. The graph of dry density 21,03 KN/m3 and the moisture content 7,30%.

4.6.2. Blended Material (30 %RAP and 70% RLS) Proctor Test

The blended material will be tested with the same procedure as the virgin material. This will allow us to compare the results. See the proctor tests result of the blended material with RLS in the table below:

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Table 4.7. Proctor results of tested blended RAP/RLS material.

Modified proctor					
Proct.n°	1	2	3	4	Val.opt
Mosture W %	4,3	7,2	8,4	10,5	7,60
Dry density δ_d KN/m ³	19,8	21,1	20,8	19,2	21,10

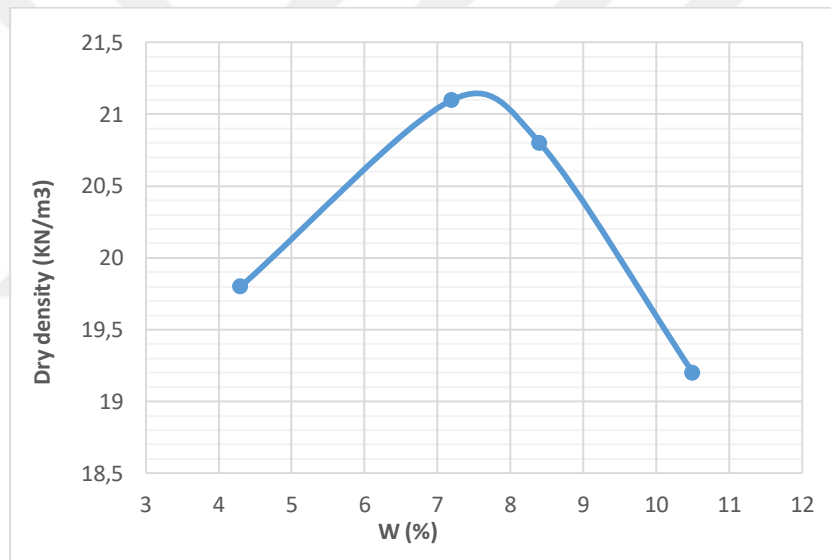


Figure 4.14. The graph of dry density 21,10 KN/m³ and the moisture content 7,60%.

4.6.3. Modified Proctor Compaction Test Conclusion

The results of the modified proctor test show that the blended material and the virgin material RLS have almost the same behavior of relationship between the moisture content and the dry density. This also proves that the mixed material agrees with the material standard used in road construction.

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4.7. C B R (California bearing ratio) imbibed at 4 day - NF P 94 – 078

CBR tests were conducted as per NF P 94 – 078) on representative laterite sample and selected 30% reclaimed asphalt 70% RLS materials in order to check the suitability of these materials for subbase course in pavement systems.

The CBR test give (the suitability of materials to withstand loads) for the embankments and layers of compacted forms of road works. It is a matter of experimentally determining California bearing ratio (IPI, CBR) which allow

- ✓ To establish a soil classification (GTR)
- ✓ Assess the trafficability of earth-moving machinery (IPI)
- ✓ Determine the pavement thickness (CBR increases $\Rightarrow$ thickness decreases)

Materials	W%	δd KN/m ³
RLS (Representative sample of laterite)	7,30	21,03
Blended material (30 %RAP and 70% RLS)	7,60	21,10

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Figure 4.15. Picture of laboratory work CBR test.

4.7.1. RLS (Representative sample of laterite) CBR Test

The CBR test is performed with an imbibition of 4 days which gives us the behavior of laterite in the worst conditions in tropical zone.

The table below details the different results of cbr test:

Table 4.8. CBR results detail of tested RSL virgin material.

CBR soaked			N.	δd KN/m ³	CBR Index		Moisture content	swelling%
90%	95%	100%			Unsoaked	soaked		
90%	95%	100%	55	21,03		110,49	9,3	0,05
24,13	62,5	110,5	25	20,1		62,52	10,4	0,08
			10	19,1		24,13	11,2	0,10

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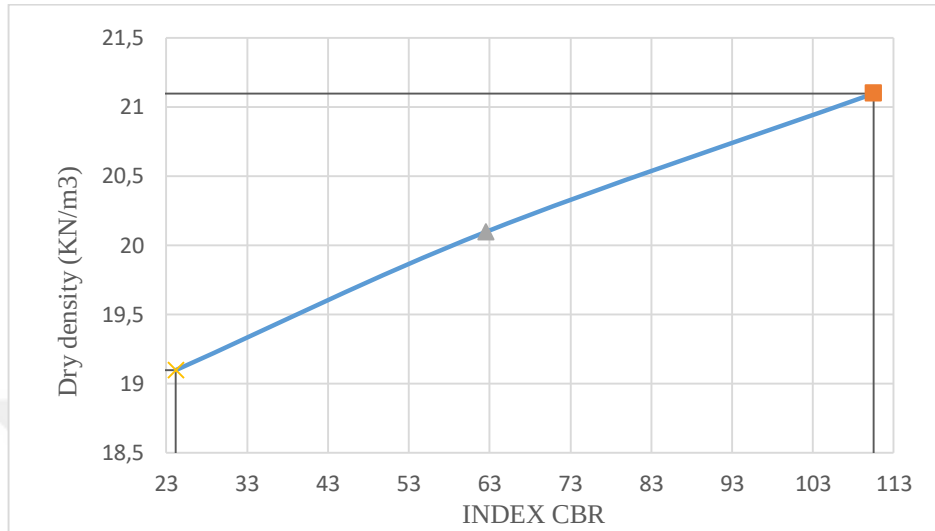


Figure 4.16. Relationship between cbr index and dry density of tested virgin material.

4.7.2. Blended Material (30 %RAP and 70% RLS) CBR Test

The cbr test of the blended material was also carried out under the same conditions as that of the laterite.

CBR soaked			N.	$\bar{\sigma}_d$ KN/m ³	CBR Index		Moisture content	swelling%
					Unsoaked	soaked		
90%	95%	100%	55	21,1		103,7	8,2	0,01
33	60,0	103,7	25	20,1		60	8,5	0,01
			10	19		33	9,4	0,02

Table 4.9. CBR results detail of tested blended RAP/RL material.

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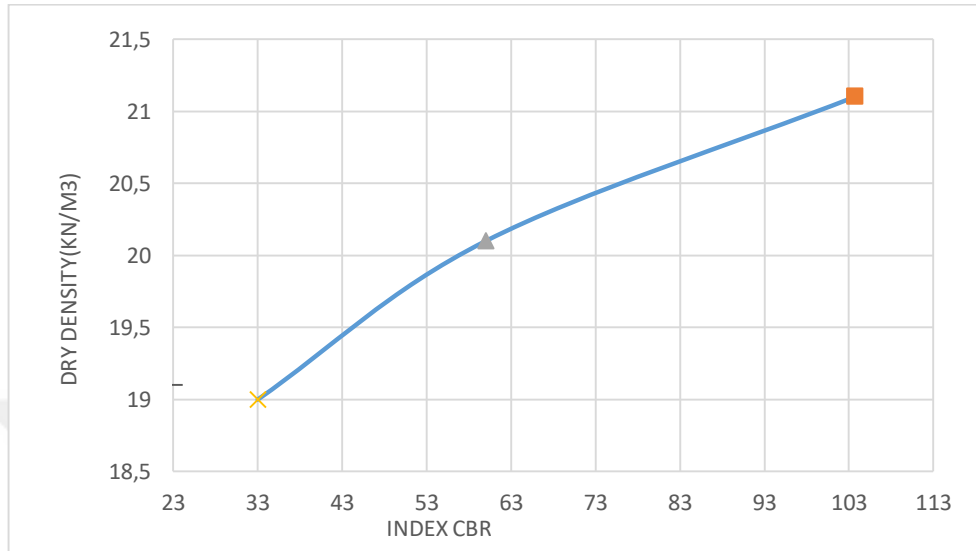


Figure 4.17. Relationship between cbr index and dry density of tested blended material.

4.7.3. C B R (California bearing ratio) Test Conclusion

The CBR values and the density values of the two materials, we observe approximately the same values. On the other hand, for the swelling values, we observe that the blended material resists more with very minimal swelling values which is perfectly expected because the asphalt does not absorb water.

In conclusion the blended material fulfilled the specifications of the materials usable in the subbase layer of a road.

4.8. Conclusion

The laboratory work allowed us to make a complete analysis of laterite as (virgin materials) and compare it to our blended material (waste material). As detailed in the previous steps we have made 4 (four) primordial geotechnical tests of road construction in tropical areas, the tests conducted are: particle size distribution test, atterberg limits, Modified Proctor and CBR test. The results of the tests on the laterite and those of the blended material have been compared and have given

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approximatively the same results, it allows us to conclude that our blended material can be used safely in road construction in the tropical zones.

The table below details all laboratory test results performed on the naturel ground soil, RLS (representative laterite sample) and the blended material:



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Table 4.10.Details of all laboratory test results performed on the naturel ground soil, RLS(representative laterite sample) and the blended material

Soil Identification	Passing to100%	% des inferieur à				Limite		E S	Proctor Modif		C B R Imbibed at 4 day			Classification
		5mm	2mm	0,4mm	0,080mm	WL	IP		δd	W	90%	95%	100%	
Natural existing ground (Gray clay)	100%	98,8	96,9	83,5	58,1	47,8	22,8		17,17					
RLS (Representative lateritic soil)	20mm	98,8	96,9	83,5	58,1	47,8	22,8		KN/m3	14,7	-	14	-	A - 7 - 6
Blended subbase material	25mm	79,8	51,3	35,5	22,6	25,1	5,9		21,10	7,6	33	60	103,7	A - 2 - 5

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4.9. Blended Sub Base Layer Thickness Calculation

The designing of the sub base layer will allow us to find the thickness required for our blended material in the road subbase construction. After determining the thickness, we can estimate the quantity of reclaimed asphalt to be used and consequently we can determine the economic impact that the using of the asphalt waste can have in the budget of the road construction.

The method used in road construction to design road layers in tropical areas is the CBR method, which is a semi-empirical method based on a punching test on a compacted soil sample at the optimum a (90-100%).

Typical procedure of road sub base layer thickness calculation

The determination of the total thickness of the pavement layers to be implemented is obtained by applying the following formula:

For a particular car traffic: $TMdA \times 365 \times 1,5t < 100000 \text{ t/year}$

$$e = \frac{100 + 150 \sqrt{P}}{ICBR + 5} \text{ cm}$$

✓ For a particular car traffic: $TMdA \times 365 \times 1,5t \gg 100000 \text{ t/year}$

$$e = \frac{100 + \sqrt{P} \times (75 + 50 \log_{10} \frac{N}{10})}{ICBR + 5} \text{ cm}$$

with:

- e = thickness
 - Icbr: CBR Index
 - N: denotes the daily number of trucks over 1500 kg empty
 - P: load by road $P = 6.5 \text{ t}$ (axle 13 t)
 - Log: decimal logarithm
- ❖ Study data:
- ✓ Year of counting: 2015
 - ✓ $TMJA_{2015} = 25737 \text{ c/d}$
 - ✓ Date of use: 2018

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- ✓ Lifetime: 20 years
- ✓ Rate of increase: $\tau = 4\%$
- ✓ Percentage of heavy truck: $Z = 50\%$

❖ Division of traffic:

- ✓ $TMdA_{2015} = 25737 \text{ c/d}$
- ✓ $TMJA_{2015} = 12868 \text{ c/d/direction}$
- ✓ $THT_{2015} = 0,50 \times 12868 = 6434 \text{ HT/d/direction}$
- ✓ $THT_{2038} = (1 + \tau)^{21} \cdot HT_{2015} = (1 + 0,04)^{21} \times 6434 = 14662 \text{ (HT/d/direction)}$

❖ Blended material: $ICBR = 33$ at 90%

$$TMdA \times 365 \times 1,5t \geq 100000 \text{ t/year} \rightarrow 25737 \times 365 \times 1,5t = 14091007 > 100000 \text{ (t/year)}$$

❖ Thickness: e

$$e = \frac{100 + \sqrt{P} \times (75 + 50 \log \frac{N}{10})}{ICBR + 5} = \frac{100 + \sqrt{6,5} \times (75 + 50 \log \frac{12868}{10})}{33 + 5} = \frac{687,712}{38} = 18,10$$

$$e = 18,10 \text{ cm} \approx 20 \text{ cm}$$

The cbr method with a cbr index = 33 of the blended material gives a thickness $e = 20 \text{ cm}$ for the soil support (blended materials), which corresponds exactly to the thickness used in place with the virgin material laterite. The result also confirms that the blended material can be used as a road sub base material.

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5. INVESTIGATION OF RECLAIMED ASPHALT AS A ROAD BASE MATERIAL

5.1. Research Methods

In this second stage of our research, we will also take the same steps as the previous one, this involves first testing the virgin material used in road construction as a base material to have the exact values which will constitute a reference to compare the Values of reclaimed asphalt. In the region the material used in the base layer is crushed aggregate 0-31.5. So these aggregate will be our reference virgin material on which to base our research. The research will be carried out in two stages for each test: the first step is testing the local virgin aggregate to determine the properties and in the second step we will test the reclaimed Asphalt.

5.2. Laboratory Tests

The different tests carried out in this research according to the Afnor standards are:

- Particle size distribution - NF P 94 - 056
- Atterberg limit (W L) – NF P 94 - 051
- Modified proctor - NF P 94 - 093
- C B R Immersed at 4 day - NF P 94 – 078

5.3. Particle Size Distribution for Road Base Materials

Cameroon, as in many African countries, the criteria of selecting materials for road construction are based on the recommendations of the "Pavement Design Guide for Tropical Countries" Of the Experimental Center of Building and Public Works (CEBTP) of 1972 and 1980 (revised in 1984). This guide is currently the most widely used. These recommendations are based on the plasticity index (PI), particle

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size and CBR. However, given the local experience, certain modifications are made to these rules depending on the road projects.

The selection criteria for the materials are defined in the table below:

Table 5.1. Base material properties

Sieve (mm)	% maxi	% mini
31,5	100,0	95,0
20,0	90,0	60,0
10,0	75,0	45,0
5,00	60,0	35,0
2,00	45,0	20,0
1,00	35,0	12,0
0,080	12,0	4,0

$\delta d \geq 2 \text{ g / cm}^3$ Plasticity index $IP \leq 15 \%$ Swelling $\leq 1\%$

The minimum and maximum distribution of the particle size represents the minimum and maximum particle distribution that a material intended to be used in the base layer of a road may have.

The tables below show the graphs of the minimum and maximum of the distribution

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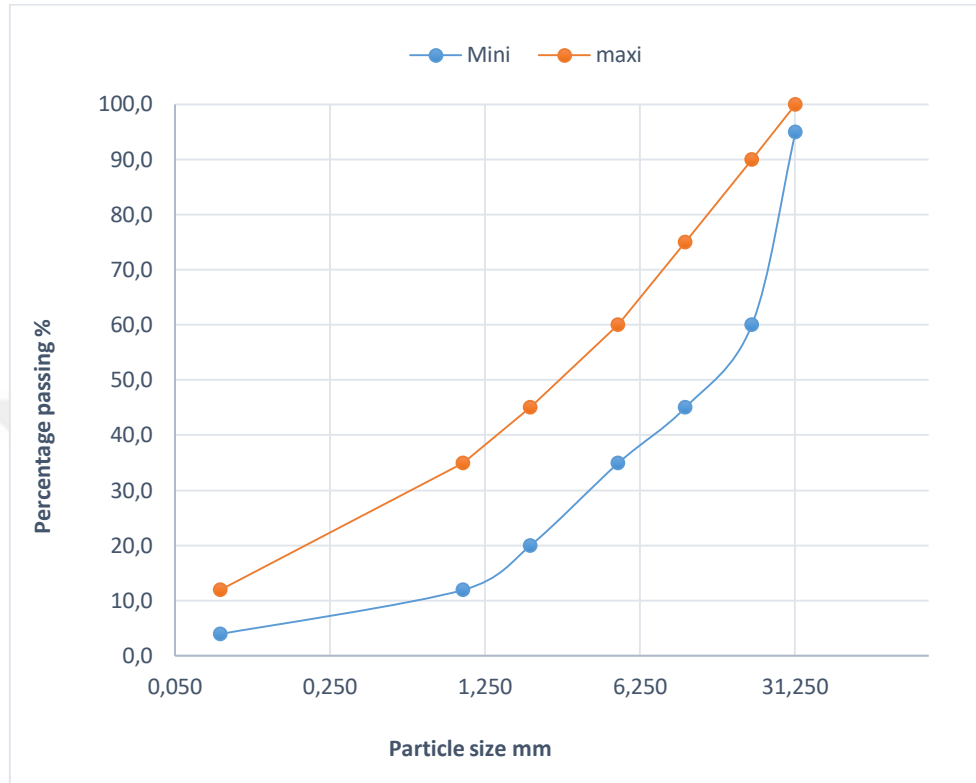


Figure 5.1. Minimum and Maximum curves of particle distribution size.

All the curves of the materials intended to be used in the base layer of a road must pass between these curves, they fix the granular limits

5.3.1. Particle Size Distribution of the Virgin Base Aggregate (whole coming mixture 0/31,5)

The particle size test of the whole coming mixture aggregates (0-31,5) is carried out in order to see whether it will fit into the envelope of the particle size curve given in the previous specification.

In order to have a good representative sample, we used the quartz method which used to divide the material into 4 and by mixing the opposite portions, which allowed us to have a good representative sample of the material 0-31,5.

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Figure 5.2. Crushed gravel sampling.

Table 5.2. The particle size distribution of tested crushed gravel (0/31,5) material.

sieve (mm)	%passing
31,5	100
25	90
20	81,3
16	71,1
12,5	63,7
10	57,4
8	51,6
5	42,1
4	37,8
2	28,4
1	21,6
0,63	18,5
0,4	16,1
0,16	12,2
0,08	9,4

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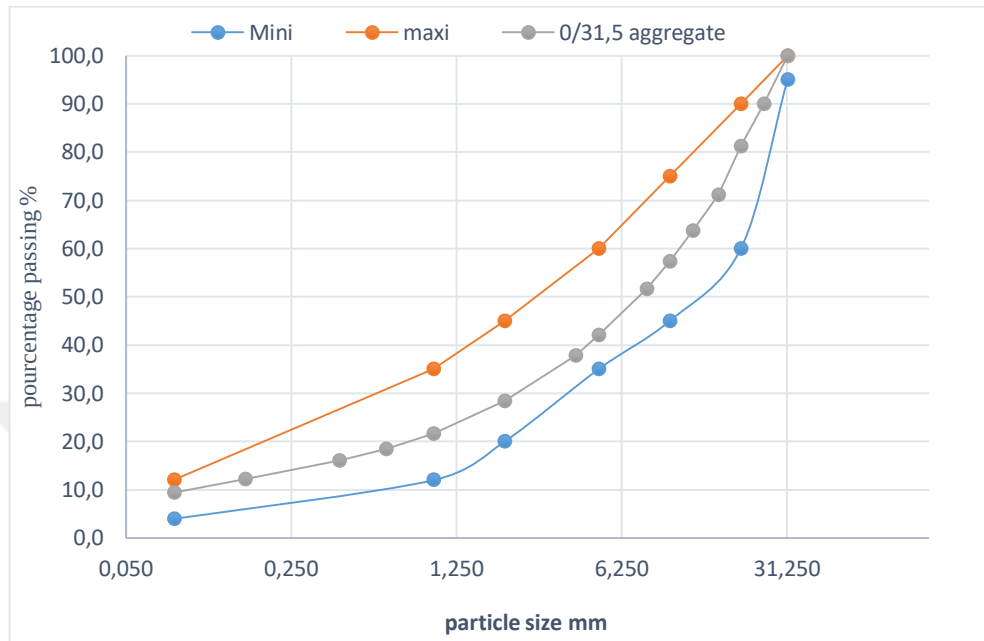


Figure 5.3. The particle size distribution graphic of tested crushed gravel.

As the graph shows the virgin aggregate 0/31,5 gives a particle size that passes between the minimum and the maximum curves. Therefore, the sample is a good material for road base. The analysis results of this sample constitute for us a good reference for the continuation of our research.

5.3.2. Particle Size Distribution of Reclaimed Asphalt Materials

The particle size test on the reclaimed asphalt will allow us to see if the reclaimed asphalt particle size curve will pass between the minimum and maximum curves specified for the road base material.

The table below contains the particle size distribution of the reclaimed asphalt.

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Figure 5.4. Crushed gravel particle size test pictures.

Table 5.3. Particle size distribution of tested reclaimed asphalt material

Sieve (mm)	Modules	Mass cumul (g)	% retained	% passing
20	44	0	0	100
16	43	215,6	2,9	97,1
12,5	42	940,7	12,8	87,2
10	41	2073,7	28,1	71,9
8	40	3380,8	45,8	54,2
5	38	5036,7	68,3	31,7
4	37	5550,0	75,3	24,7
2	34	6391,5	86,7	13,3
1	31	6841,9	92,8	7,2
0,63	29	7010,1	95,1	4,9
0,4	27	7124,9	96,6	3,4
0,16	23	7268,4	98,6	1,4
0,080	20	7333,1	99,4	0,6

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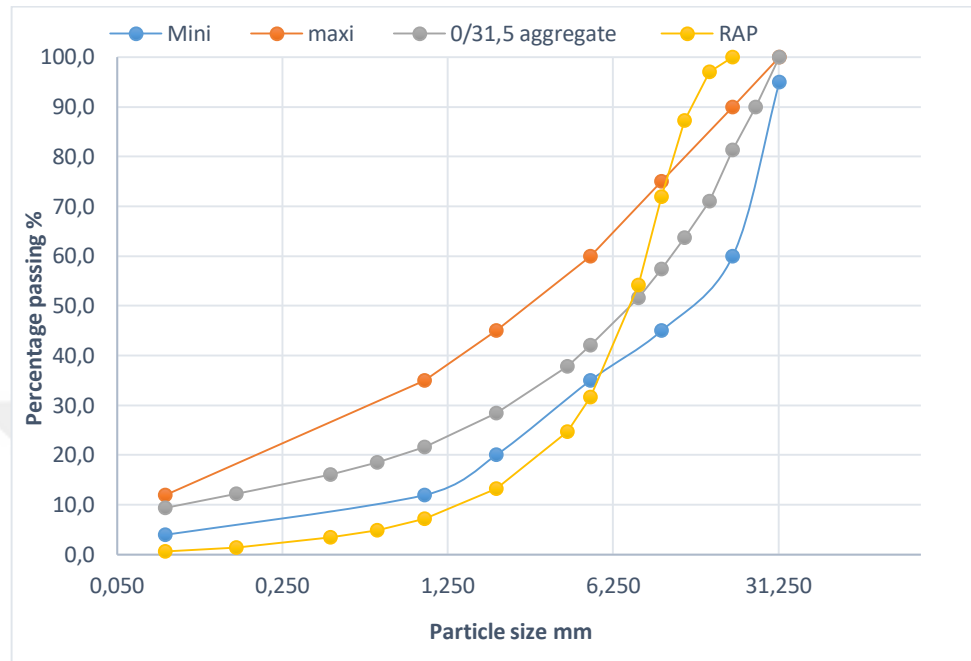


Figure 5.5. Particle size distribution graphic of tested reclaimed material.

The result of the particle size test of reclaimed asphalt shows that the graph of the RAP material does not pass between the minimum and maximum curves, it can be concluded that the RAP material cannot be used as a road base material.

In order to reuse the RAP material in the road construction, a particle size improvement of this material is required. We will try to improve the RAP material by blending it with the virgin aggregate of 0/31,5.

5.4. Amelioration of the RAP Materials by Blending with Local Virgin Crushed Gravel Material (0-31,5)

In order to reuse the reclaimed asphalt material in the base layer of road, a particle size improvement of this material is required. We will try to improve the reclaimed asphalt material by blending it with the virgin 0-31,5 material.

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5.4.1. Blending Method

The improvement of reclaimed asphalt particles distribution consists of blending the reclaimed asphalt with local virgin material (0-31,5). This makes the possibility to bring the size of the reclaimed asphalt to the required size and the appropriate classification required for the base layer according to the specifications NF P 94 – 056.

Samples of different compositions were prepared by adding different percentage of reclaimed asphalt (RAP) materials (50% RAP, 38%RAP, 35%RAP,30%RAP).



Figure 5.6. Blended RAP/Crushed gravel (0/31,5)

5.4.2. Blending materials Particles sieving result

Samples of different compositions were prepared by adding different percentage of reclaimed asphalt materials (50%RAP, 38%RAP, 35%RAP, 30%RAP).

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Details of samples blending:

Asphalt + local virgin crushed gravel material (0-31,5) = 5 kg

- **100% RAP (reclaimed asphalt)**

RAP = 5 kg See the results in the preceding table

- **50% RAP**

Blending of 2,5 kg of RAP + 2,5 kg of crushed gravel 0-31,5

- **38% RAP**

Blending of 1,90 kg RAP + 3,10 kg of crushed gravel 0-31,5

- **35% RAP**

Blending of 1,75 kg of RAP + 3,25 kg of crushed gravel 0-31,5

- **30% RAP**

Blending of 1,5 kg of RAP + 3,5 kg of crushed gravel 0-31,5

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Table 5.4. Particle size distribution of tested blended material

Sieve (mm)	100% RAP	50% RAP	38%RAP	35% RAP	30% RAP
31,5		100	100	100	100
25		99,4	96,9	95,7	95,9
20	100	94	89,4	87,3	82
16	97,1	89,2	82,7	79,2	72,1
12,5	87,2	79,8	71,3	69,7	61,6
10	71,9	72	61,2	61,1	52,2
8	54,2	61,4	49,8	52,9	42,3
5	31,7	45,8	34,4	39,3	29,8
4	24,7	40,1	28,4	34,1	24,7
2	13,3	26,9	17,6	22,4	14,7
1	7,2	17,7	10,9	14,1	8,6
0,63	4,9	13,3	8	10,4	6,1
0,4	3,4	9,8	5,9	7,7	4,4
0,16	1,4	4,4	2,7	3,6	2
0,1	0,6				
0,08	30,5	0,7	0,6	0,8	0,5

5.4.3. Blending Materials Graphics Analysis

All graphic was plotted successively in the preceding table containing the curves of the CEBTP (1980) specification for materials intended for the base layer of a road. This will enable us to appreciate the blended material curve evolution.

▪ 100% RAP (reclaimed asphalt)

RAP = 5 kg See the results in the preceding table

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▪ 50% RAP

Blending of 2.5 kg of RAP + 2.5 kg of crushed gravel 0-31,5

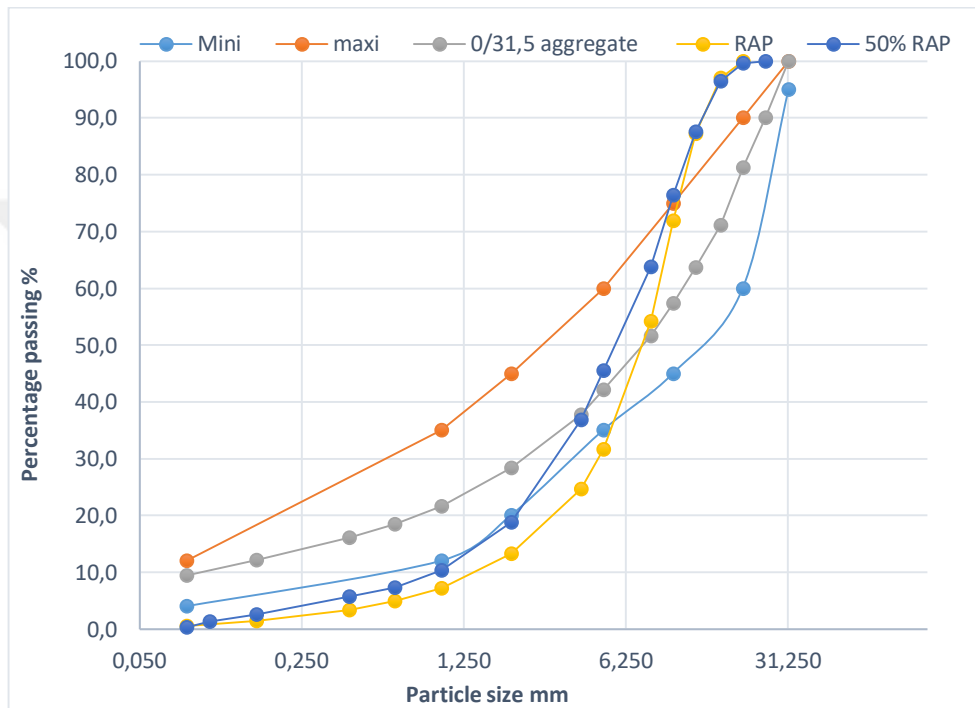


Figure 5.7. Particle size distribution curve of 50% RAP.

For 50% reclaimed asphalt and 50% crushed gravel 0-31,5, we observe a slight improvement of the curve towards the curves envelope of the CEBTP (1980) specification. The lower part of the curve is slightly improved while the upper part remains always unchanged.

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▪ 38% RAP

Blending of 1,90 kg RAP + 3,10 kg of crushed gravel 0-31,5

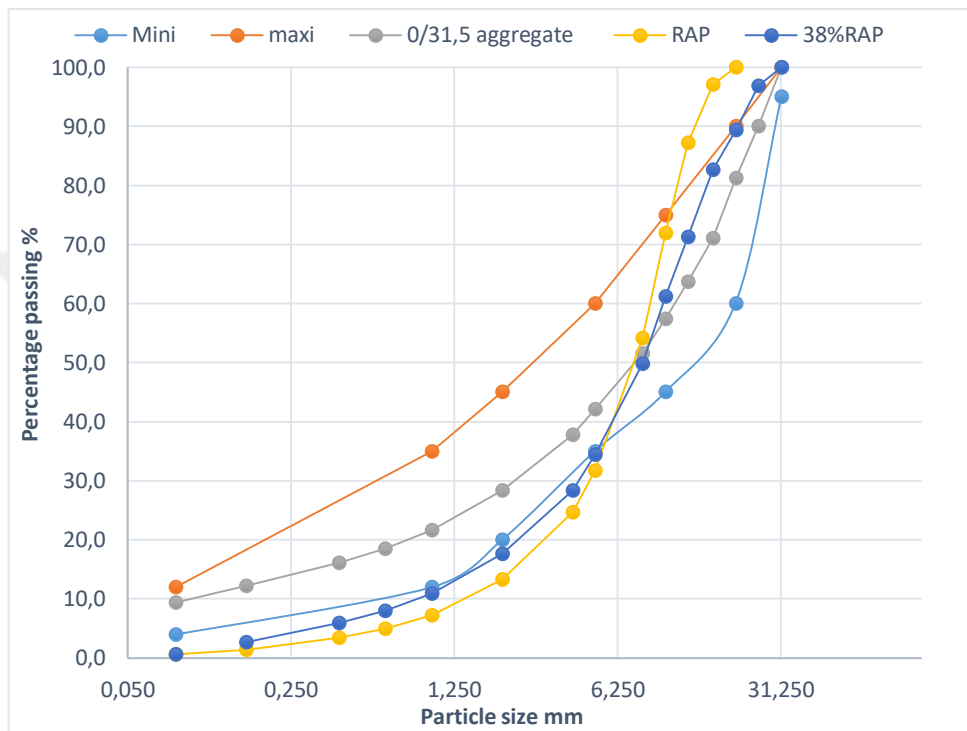


Figure 5.8. Particle size distribution curve of 38% RAP.

The blending of 38% reclaimed asphalt and 62% crushed gravel 0-31,5 give a good improvement of the curve. A good improvement of the two parts of curve is observed, the natural material begins to improve the particle distribution of the RAP.

▪ 35% RAP

Blending of 1,75 kg of RAP + 3,25 kg of crushed gravel 0-31,5

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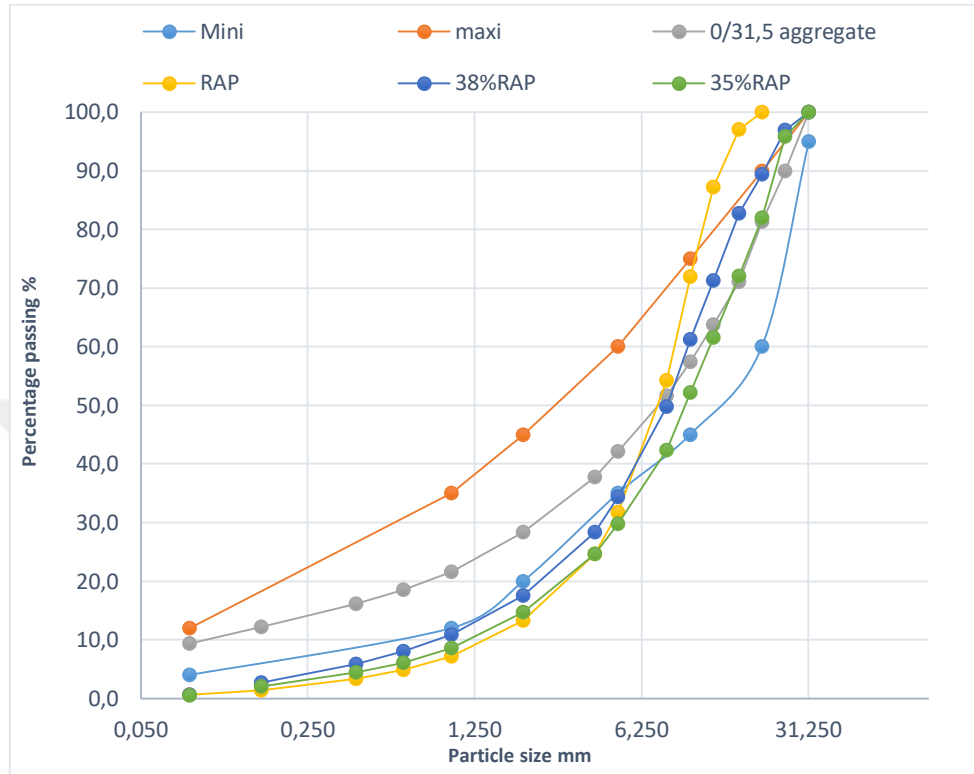


Figure 5.9. Particle size distribution curve of 35% RAP.

The blending of 35% reclaimed asphalt and 65% crushed gravel 0-31,5 give a good improvement of the curve but still out of the specification curves envelope.

▪ 30% RAP

Blending of 1,5 kg of RAP + 3,5 kg of crushed gravel 0-31,5

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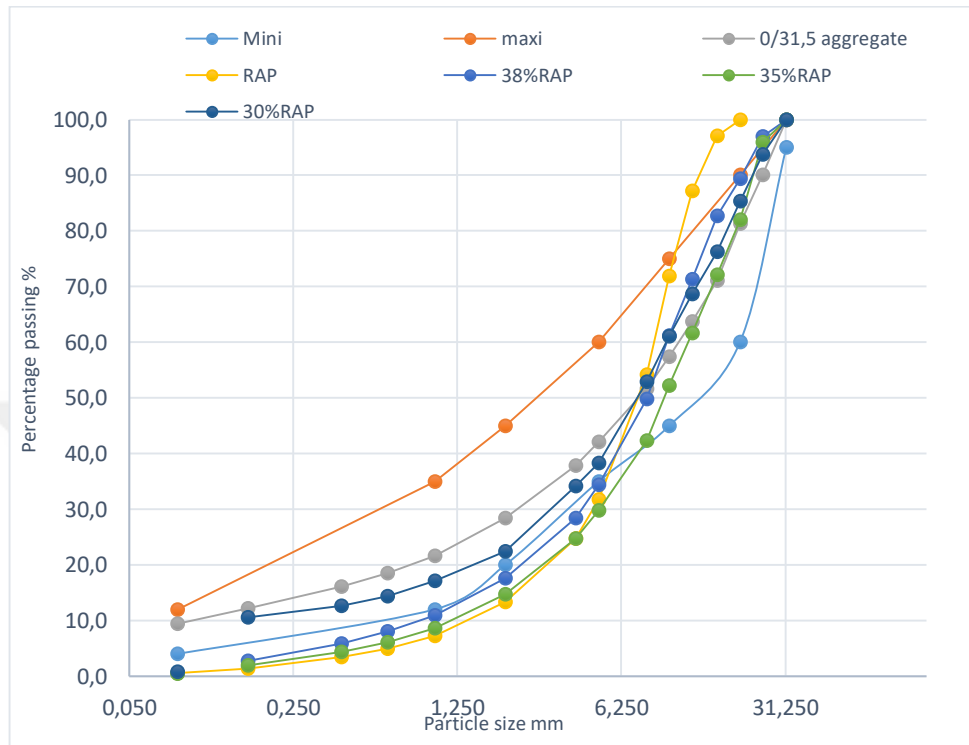


Figure 5.10. Particle size distribution curve of 35% RAP.

The mixture of 30% reclaimed asphalt and 70% crushed gravel 0-31,5 give a curve that enters in the specification envelope curves which constitutes the tolerance zone and come toward the curve of the virgin 0-31,5 material. The particle size distribution of this mixture corresponds to the prescribed standard of the materials intended for the base layer.

5.5. Particle Size Test Conclusion

The graphic table, the mixture of 30% reclaimed asphalt and 70% 0-31,5 gives us a curve closest to the curve of the virgin sample. The material '30% RAP and 70% 0-31,5' gives us a curve that has a distribution of particles appropriate to the base layer of a road according to standard NF P 94-056 and CEBTP (1980)

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specification, Therefore the material '30% RAP and 70% 0-31,5 will be our materials on which we will conduct the different tests.

The tests conducted on the '30% RAP and 70% 0-31,5 will be compare to the different result lead on the virgin sample. Blending of RAP by adding different percentage of virgin materials allows the curve to progress towards the specification curves. As shown in the table.

Table 5.5. The particle size distribution of blended 30% RAP and 70% Crushed gravel.

Sieve (mm)	30% RAP
31,5	100
25	93,7
20	85,3
16	76,2
12,5	68,7
10	61,1
8	52,9
5	38,3
4	34,1
2	22,4
1	17,1
0,63	14,4
0,4	12,7
0,16	10,6
0,1	5,5
0,08	0,8

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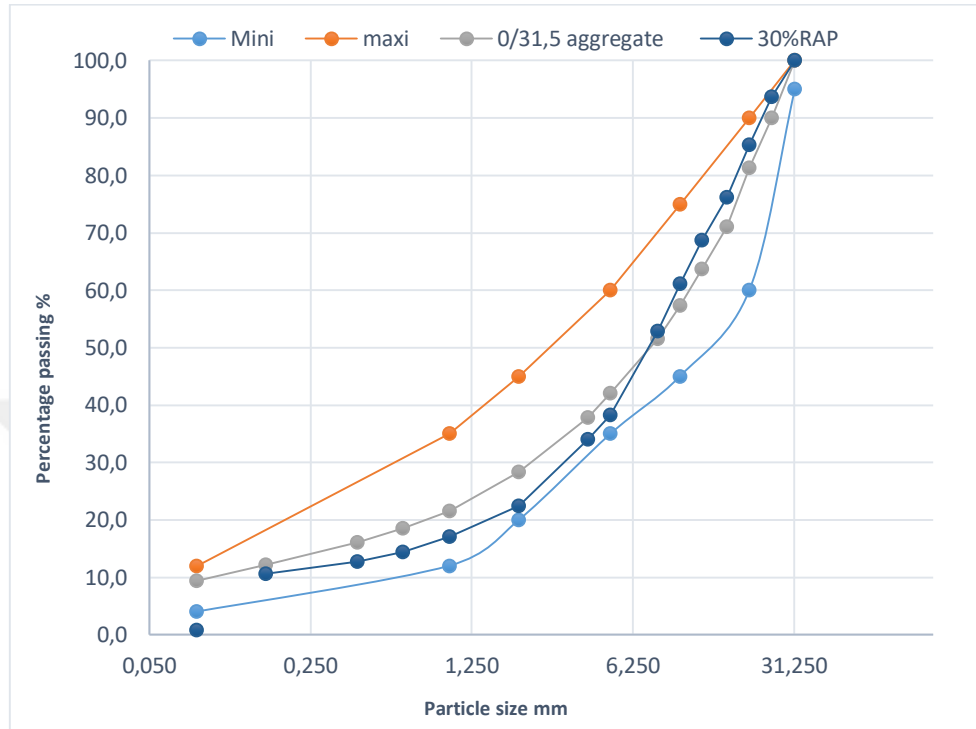


Figure 5.11. The particle size distribution curve of blended 30% RAP and 70% Crushed gravel.

5.6. Atterberg Limit (w_l) – NF P 94 – 051

The purpose of these tests is to determine the consistency limits that are expressed in terms of water content marking the boundaries between solid state, plastic, and liquid. It is important to note that these tests apply only to fine soils, defined as grains with diameters less than 0.08 mm.

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Figure 5.12. Atterberg limit test picture.

5.6.1. Virgin Material (0-31,5) Atterberg Limit Test

The test of atterberg limit on the Virgin crushed gravel material gives us the following results:

WL	WP	IP
24,6	18,6	6,0

5.6.2. Blended Material (30 %RAP and 70% 0-31,5) Atterberg Limit Test

The test of atterberg limit on the Blended material (30 %RAP and 70% crushed gravel 0-31,5) gives us the following results:

WL	WP	IP
22,3	17,5	4,8

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5.6.3. Atterberg Limit Test Conclusion

The plasticity index $I_p = WL - WP$ allows us to characterize the clay content of a soil. According to the GTR classification. $0 < IP < 12$ low clay content.

According to this classification the two materials contain little clay and are in the same class.

5.7. Modified Proctor Compaction Test -NF P 94 - 093

Modified Proctor Compaction test (NF P 94 - 093) was performed on the virgin material sample and selected 30% reclaimed asphalt 70% 0,31,5 materials to determine the relationship between the moisture content and the dry density for a specified compactive effort.



Figure 5.13. Modified Proctor test picture.

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5.7.1. Virgin Material (0-31,5) Proctor Test

Plot the moisture content versus dry density on graph paper with the vertical side representing dry density in kg/m^3 and the horizontal side representing moisture content in percentages.

To have the maximum dry density and the moisture content of 0-31,5 three proctor tests are necessary (see the result in the table)

Table 5.6. Proctor results of tested virgin crushed gravel material.

Modified Proctor 0-31,5					
P.n°	1	2	3	4	Val.opt
W %	2,7	4,6	6,7	8,7	6,4
$\delta_d \text{ KN/m}^3$	21,5	21,6	21,7	21,5	21,7

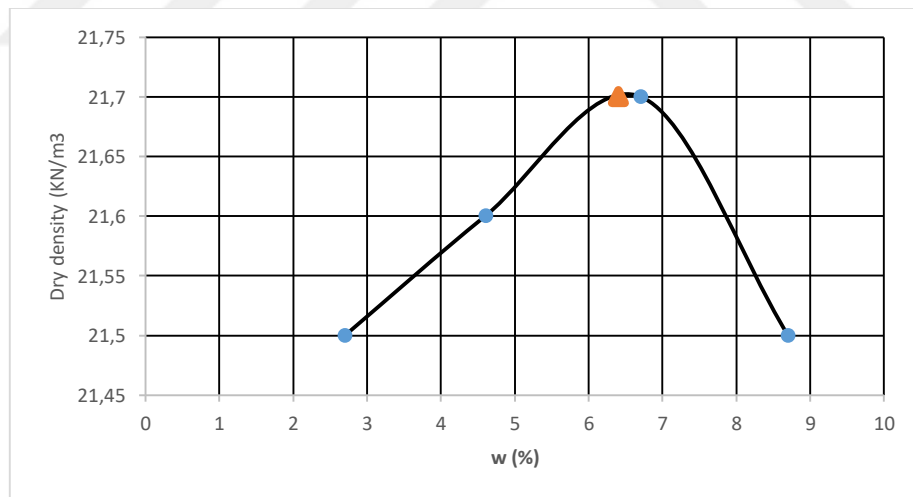


Figure 5.14. The graph gives us dry density 21,70 KN/m^3 and the moisture content 6,40%.

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5.7.2. Blended Material (30 %RAP and 70% 0-31,5) Proctor Test

The blended material will be tested with the same procedure as the virgin material. This will allow us to compare the results. See the proctor tests result of the blended material samples in the table below:

Table 5.7. Proctor results of tested virgin crushed gravel material.

Modified Proctor 30 %RAP and 70% crushed gravel 0-31,5					
P.n°	1	2	3	4	Val.opt
W %	4,2	6,5	8	10,5	7,3
δ_d KN/m ³	20,8	21,3	21,3	20,7	21,35

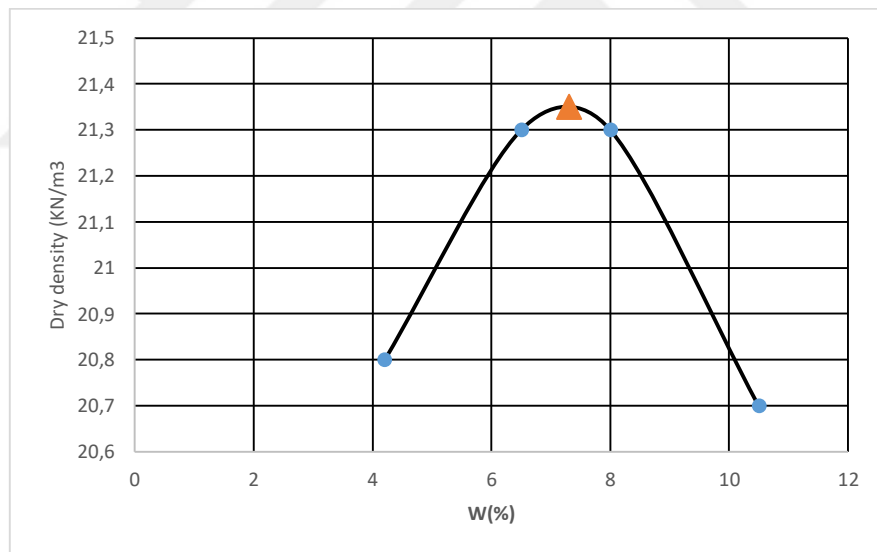


Figure 5.15. The graph gives us dry density 21,35 KN/m³ and the moisture content 7,30%.

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5.7.3. Modified Proctor Compaction Test Conclusion

The results of the modified proctor test show that the blended material and the virgin material 0-31,5 have almost the same behavior of relationship between the moisture content and the dry density. This also proves that the mixed material agrees with the material standard used in road construction.

Table 5.8. Proctor results of tested materials.

Materials	W%	δ_d KN/m ³
0-31,5 virgin material)	6,4	21,7
Blended material (30 %RAP v 70% 0-31,5)	7,3	21,35

5.8. C B R (california bearing ratio) Immersed at 4 day - NF P 94 – 078

CBR tests were conducted as per NF P 94 – 078) on 0-31,5 material sample and selected blended material (30% reclaimed asphalt 70% 0-31,5) in order to check the suitability of these materials for base course in pavement systems.

As previously mentioned the CBR test give (the suitability of materials to withstand loads) for the embankments and layers of compacted forms of road works. It is a matter of experimentally determining California bearing ratio (IPI, CBR) which allow

- To establish a soil classification (GTR)
- Assess the trafficability of earth-moving machinery (IPI)
- Determine the pavement thickness (CBR increases $\Rightarrow$ thickness decreases).

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Figure 5.16. C b r (california bearing ratio).

5.8.1. Virgin Crushed Gravel (0-31,5) CBR Test

The cbr test is performed with an imbibition of 4 days which gives us the behavior of the virgin material 0-31,5 in the worst conditions in tropical zone.

The table below details the different results of cbr test:

Table 5.9. CBR test results of crushed gravel.

CBR soaked			N	δd KN/m ³	CBR Index		Moisture content	swelling%
					Unsoaked	soaked		
90%	95%	100%	55	21,7		177	6,1	0,00
27,4	52,6	177,0	25	20,7		52,6	4,6	0,01
			10	19,6		27,4	4,8	0,76

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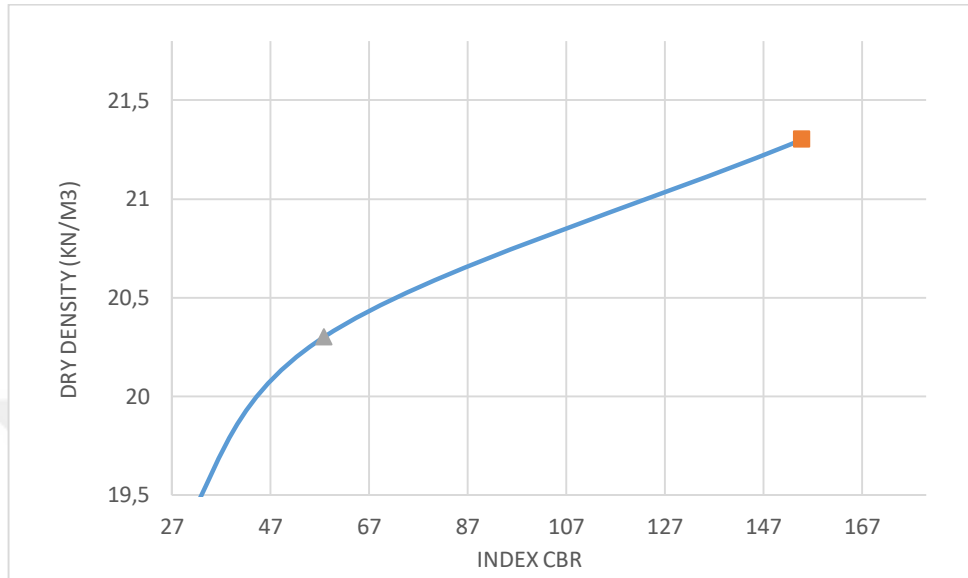


Figure 5.17. Relationship between Density and cbr index curve of crushed gravel material.

5.8.2. Blended Material (30 %RAP and 70% 0-31,5) CBR Test

The cbr test of the blended material was also carried out under the same conditions as that of the crushed gravel .The table below details the different results of cbr test:

Table 5.10. CBR test results of blended (30 %RAP and 70% 0-31,5) material.

CBR soaked			N	δd KN/m ³	CBR Index		Moisture content	swelling%
90%	95%	100%			Unsoaked	soaked		
90%	95%	100%	55	21,3		154,9	6,2	0,00
26,2	57,8	154,9	25	20,3		57,8	4,2	0,01
			10	19,2		26,2	4,4	0,02

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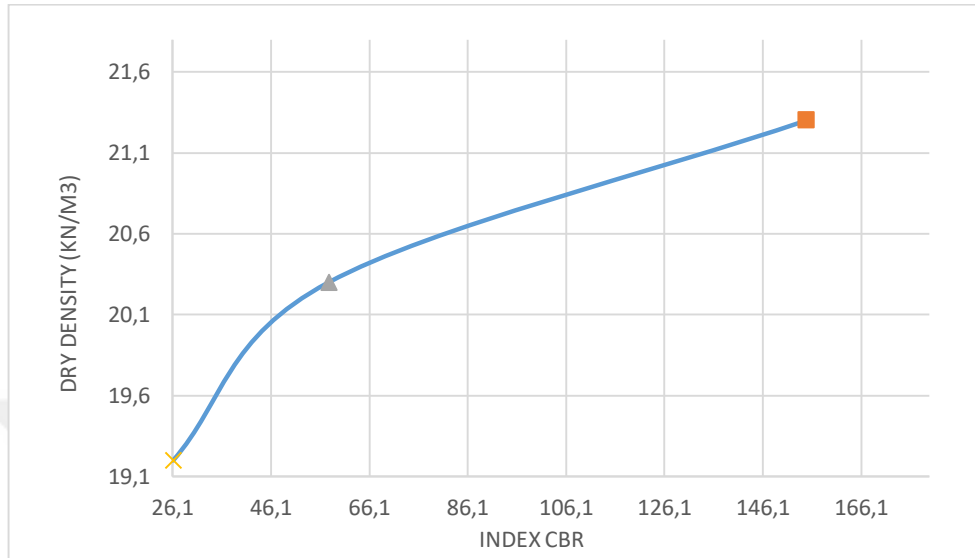


Figure 5.18. Relationship between dry density and cbr index curve of blended material

5.8.3. C B R (california bearing ratio) Test Conclusion

Results Interpretation of the CBR test for the two materials: For the CBR values and the density values of the materials, we observe approximately the same values. On the other hand, for the swelling values, we observe that the blended material resists more with very minimal swelling values which is perfectly expected because the asphalt does not absorb water. The behavior of the blended materials and the virgin material used in the base layer are identical. In conclusion the blended material fulfilled the specifications of the materials usable in the base layer of a road.

5.9. Conclusion

As in the previous process the laboratory work allowed us to make a complete analysis of 0-31,5 as (virgin materials) and compare it to our blended material (waste material). As detailed in the previous steps we have made 4 (four) primordial geotechnical tests in road construction in tropical areas, the tests

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conducted are: particle size distribution test, atterberg limits, modified Proctor and CBR test.

The results of the tests on the 0-31,5 materials and those of the blended material have been compared and have given approximatively the same results, it allows us to conclude that our blended material can be used safely in road construction in the tropical zones. The table below details all laboratory test results performed on the naturel ground soil, 0-31,5(virgin sample) and the blended (30%RAP vs 70% 0-31,5) material:



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Table 5.11. Details of all laboratory test results performed on the naturel crushed gravel 0-31,5 soil and the blended material.

Soil Identification	Passing to 100%	% des inferieur à				Limite D'Atterb		E S	Proctor Modif		C B R Imbibed at 4 day			Classification
		5mm	2mm	0,4mm	0,080mm	WL	IP		δd	W %opt	90%	95%	100%	
Natural existing ground (Gray clay)	20mm	98,8	96,9	83,5	58,1	47,8	22,8		1,717 t/m3	14,7	-	14	-	A - 7 - 6
Base virgin materials (0-31,5 mm)	31,5 mm	42,1	20,4	16,1	9,4	24,6	6		2,17	6,4	27,4	52,6	177	A - 2 - 5
Base blended material (30% RAP & 70%0-31,5)	31,5mm	38,3	22,4	12,7	0,8	22,3	4,8		2,135	67,3	26,2	57,8	154,9	A - 2 - 6

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5.10. Blended Base Layer Thickness Calculation

The designing of the sub base layer will allow us to find the thickness required for our blended material in the road base construction. After determining the thickness, we can estimate the quantity of reclaimed asphalt to be used and consequently we can determine the economic impact that the using of the asphalt waste can have in the budget of the road construction.

The method used in road construction to design road layers in tropical areas is the CBR method, which is a semi-empirical method based on a punching test on a compacted soil sample at the optimum a (90-100%).

➤ Typical procedure of road sub base layer thickness calculation

The determination of the total thickness of the pavement body to be implemented is obtained by applying the following formula:

For a particular car traffic: $TMdA \times 365 \times 1,5t < 100000 \text{ t/year}$

$$e = \frac{100 + 150 \sqrt{P}}{ICBR + 5} \text{ cm}$$

✓ For a particular car traffic: $TMdA \times 365 \times 1,5t \gg 100000 \text{ t/year}$

$$e = \frac{100 + \sqrt{P} \times (75 + 50 \log_{10} \frac{N}{10})}{ICBR + 5} \text{ cm}$$

with:

- e = thickness
- Icbr: CBR Index
- N: denotes the daily number of trucks over 1500 kg empty
- P: load by road $P = 6.5 \text{ t}$ (axle 13 t)
- Log: decimal logarithm

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❖ Study data:

- ✓ Year of counting: 2015
- ✓ $TMJA_{2015} = 25737 \text{ c/d}$
- ✓ Date of use: 2018
- ✓ Lifetime: 20 years
- ✓ Rate of increase: $\tau = 4\%$
- ✓ Percentage of heavy truck: $Z = 50\%$

❖ Division of traffic:

- ✓ $TMdA_{2015} = 25737 \text{ c/d}$
- ✓ $TMJA_{2015} = 12868 \text{ c/d/direction}$
- ✓ $THT_{2015} = 0,50 \times 12868 = 6434 \text{ HT/d/direction}$
- ✓ $THT_{2038} = (1 + \tau)^{21} \cdot HT_{2015} = (1 + 0,04)^{21} \times 6434 = 14662 \text{ (HT/d/direction)}$

❖ Blended material: $ICBR = 26,2$ at 90%

$$TMdA \times 365 \times 1,5t \geq 100000 \text{ t/year} \rightarrow 25737 \times 365 \times 1,5t = 14091007 > 100000 \text{ (t/year)}$$

❖ Thickness: e

$$e = \frac{100 + \sqrt{P} \times (75 + 50 \log \frac{N}{10})}{ICBR + 5} = \frac{100 + \sqrt{6,5} \times (75 + 50 \log \frac{12868}{10})}{26,2 + 5} = \frac{687,712}{31,2} = 22 \text{ cm}$$

$$e = 22 \text{ cm}$$

The cbr method with a cbr index = 26,2 of the blended material gives a thickness $e = 22 \text{ cm}$ for the soil support (blended materials). The thickness applied to the project in place is 20 cm for the base layer, the thickness required for the

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blended material gives us 22 cm, a difference of 2 cm is observed which can be explained by calculation error during tests.



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6. APPLICATIONS AND LIMITATIONS

6.1. Reclaimed Asphalt Material in Road Construction

Generally, reclaimed asphalt material is successfully reuse in road construction and maintenance materials. But reusing of reclaimed materials involves consideration of several interacting elements:

- ✓ The reclaimed asphalt materials must have suitable engineering properties for the intended reuse,
- ✓ RAP materials must be sufficient quantities of available to economically justify their reuse,
- ✓ The RAP materials must not have any potentially harmful environmental impacts with the reuse activity.

It is also important to appreciate and adopt the concept of 'highest-best use' in selecting the technically most appropriate, and environmentally most sustainable, reuse options for road construction and maintenance materials. This concept is based on the premise that the best use of a material is in that which the material has the highest value. For instance, the best use for reclaimed asphalt pavement (RAP) is in applications where the full value of both the asphalt binder and the aggregates is realized.

Recycling of reclaimed asphalt pavement (RAP) can result in significant reductions in both the amounts of new asphalt binder and new aggregate required for pavement construction, and reduced energy consumption. However, while the use of RAP as granular base or subbase does reduce the amount of new granular material required, the value of the asphalt cement as a binder and the energy invested to produce it is lost. Similarly, recovered concrete aggregates should, wherever possible, be reused as construction aggregates, thereby decreasing the demand for new aggregates.

6.2. Engineering RAP Materials Considerations

In order to be considered for reuse, the reclaimed materials must have, or be properly processed to have, suitable engineering properties for the intended application. Generally, reclaimed materials with the highest potential for general use as construction aggregates will have adequate (equivalent to natural aggregates) soundness, hardness, gradation and particle shape, resistance to chemical and physical deterioration, and require a minimum of processing such as crushing, blending and screening. It is also important to identify any potentially deleterious components in the recovered material so that their impact can be properly assessed and addressed for the reuse application being considered.

Most agencies have standard specifications that define the specific engineering, mechanical, physical and chemical requirements for any recycled materials or the products in which they are used. For instance, the materials specifications for hot-mix asphalt generally include provisions for recycled hot mix. Standard test methods (ASTM and AASHTO, for instance, as well as agency specific test methods such as Laboratory tests) are used in conjunction with the material and construction specifications to assess the physical properties and overall quality of construction aggregates.

6.3. Environmental Aspect Considerations

The environmental properties of the recovered materials must be evaluated through proper sampling and testing in accordance with applicable environmental legislation, codes/regulations and/or protocols/guidelines, to ensure that there are no potentially harmful constituents present (no leaching of toxic constituents, dust/particulate or air emissions concerns, etc.) during use in construction or following incorporation of the material in the construction application.

It is not uncommon for materials from within the public right-of way to be contaminated due to accidental spills (mainly gasoline or diesel fuel near accident locations), leakage of buried utilities or from adjacent sites, or vehicle exhaust

emissions (particularly in areas where leaded fuels may have been used). It should also be recognized that the environmental regulations and health and safety practices vary somewhat across depending on the country, and it is important that the local requirements be applied. For instance, the City of Toronto limits the amount of asbestos fiber (chrysotile) in an existing asphalt mixture to less than 2 percent by mass of asphalt cement for the asphalt concrete to be considered for recycling.

6.4. Economic and Benefits Consideration of Rap Use

The overall economic feasibility of reusing or recycling of materials recovered during road construction and maintenance is a function of the location, quantity and market for the recycled product, the technical requirements for the particular application(s), the resource replacement value of the components of the material in bulk and/or cementitious applications, and ecological and social considerations such as resource conservation and sustainable development. For instance, while it is certainly desirable from a resource conservation and sustainable development (highest-best use) viewpoint to recycle all old asphalt back into recycled asphalt mixtures for roadway pavements, and there are a wide range of options and few technical impediments to preclude such recycling, it may not be economically practical where the amount of RAP available is low or suitable asphalt plant and equipment does not exist. In such cases, the most viable option may be to reuse the RAP as aggregate in granular base or subbase, or disposal at a municipal landfill. However, when comparing the overall 'cost' of recycling, it is also important to consider not only the total life cycle costs but also the initial cost savings, if any, attributed to the use of recycled product in lieu of new material, but also the cost of disposal (tipping fee for instance) if the recovered material cannot be practically reused or recycled.

Benefits considerations, some of economic benefits of using RAP as a sustainable construction material are as follows (Carswell et al., 2005):

- ✓ The use of already existing materials
- ✓ The elimination of disposal problems
- ✓ Conservation of natural resources
- ✓ Major energy savings, including those related to avoiding processing of additional virgin material and the reduced haulage of materials
- ✓ Reduction of inconvenience attributable to traffic caused by haulage of materials

Some asphalt recycling equipment suppliers quoted potential cost savings ranging from \$30 to \$80 per ton recycled (AsphaltRecycling.com, 2013). It has been estimated that in some areas recycled materials cost less to use than conventional crushed stone base material by as much as 30% (Edil, 2011).

There are wide variations in the amount of RAP allowed in unbound layers by various transportation agencies. Although the use of 100% RAP is not isolated, the general state of the practice appears to be trending toward 50% as the maximum allowable content. Many agencies set limits at well below 50% by weight. The large variability in RAP content in unbound layers allowed by various agencies may indicate that this particular application is not the main focus of RAP recycling efforts. It can be argued that RAP material is too valuable a resource to be used in large quantities in applications other than recycling in bound asphalt mixtures.

The asphalt binder is typically the most expensive component of asphalt pavement construction and thus the most valuable and economically variable material (Copeland, 2011). It is commonly used in the production of intermediate and surface layers of flexible pavements. The focus of RAP research has been traditionally concentrated on asphalt mix design. A mixture with a high RAP content is defined as one that has 25% or more recycled material by weight. Current research efforts in pavement technology are aimed at increasing the asphalt mixture RAP content to above 30% by weight. Copeland et al. (2010) concluded that the most economical use of RAP is in asphalt mixtures that go into the intermediate and

surface layers of flexible pavements, where RAP actually replaces a portion of the more expensive virgin binder.

6.5. Limiting Factors for Increased Use of RAP

The major impediments to enhanced reuse continue to be the same as were identified in 1992 (JEGEL, 1992 and Melton, 2004):

- ✓ agency resistance to adopting new materials and construction technology
- ✓ (conservatism);
- ✓ Obsolete specifications;
- ✓ Inadequate research and development budgets;
- ✓ Liability/performance concerns over innovative technologies;
- ✓ Environmental constraints on recyclable materials that are not applied to conventional materials;
- ✓ Industry processing and pricing that are based on new materials;
- ✓ Widely scattered distribution or small quantities of potentially recyclable materials;
- ✓ Collection, storage and processing costs;
- ✓ Lack of technical guidance.



7. FIELD QUALITY-CONTROL TESTING

7.1. Reclaimed Asphalt Pavement Mixtures Testing

In most states, bituminous mixtures containing RAP are sampled and tested in the same way as virgin mixtures are sampled and tested. If there are any problems with the RAP, such as excessive moisture or variability, it is assumed that these problems will show up in the final mixture and be detected by the usual quality-assurance testing. Some additional testing of the RAP may be required by the state at the mix design stage or during construction. These requirements vary widely from state to state because they are based on each state's own experience and materials; therefore, it is important to know your state's requirements.

For example, you may be required to sample and test the RAP based on how much RAP is used—say, one sample for every 1000 Mg of RAP used. Typical tests that must be run include binder content, gradation, and moisture content tests. Consensus aggregate properties, such as coarse aggregate angularity, may also be required. Some states will waive this testing if the RAP stockpile is thoroughly tested prior to mix production.

Typical mixture acceptance tests include binder content, moisture content, gradation, voids, and VMA tests. These tests usually do not vary if RAP is included in the mixture. One exception to this rule is gradation. Some states allow the testing of belt samples or cold or hot bin samples for the aggregate gradation; with RAP mixtures, those states may choose to require the use of extracted gradations of the RAP aggregate.

7.2. Additional Quality-Control Procedures with Rap Mixtures

Although the state may not require any changes from its standard quality assurance–quality control procedures, it may be in the contractor's best interest to sample the RAP material more frequently than he or she samples the virgin aggregate.

This frequency of sampling will depend on many factors, including:

- ✓ The consistency of the RAP source,
- ✓ How the stockpiles have been managed?
- ✓ How much processing of the RAP has occurred?
- ✓ The availability of testing personnel,
- ✓ Testing costs, and
- ✓ Other factors.

Good production quality-control practices may require extra testing to ensure that the RAP has not changed enough to throw the mixture properties out of compliance with the specification targets. Certainly, if problems begin to occur with the mixture properties, the RAP is one of the potential sources of the problem and should be checked.

Testing of the RAP to ensure consistency and quality should include verifying the binder content and gradation. Variations in the RAP material would appear as changes in these properties. Moisture content of the RAP should also be verified if moisture in the mixture becomes a concern.

The frequency of testing the RAP stockpile for quality control purposes may vary, depending on many factors. A minimum frequency of testing is recommended, based either on the amount of RAP used (1 test per 1000 Mg used) or on days of production (1 test per day). Additional testing can then be performed if you suspect the RAP stockpile may be changing (you are getting into a wetter part of the pile); if problems begin to develop in the mixture properties; or for other reasons. Quality-control plans should address

- ✓ The techniques taken for processing and stockpiling the RAP to ensure consistency
- ✓ What steps will be taken if excess variability is observed.

In other words, RAP should be treated as another source of variation that needs to be monitored and controlled like the other stockpiles. If proper precautions are taken, RAP mixtures should perform at least as well as virgin mixtures.

7.3. Quality Control and Acceptance

Currently, there is no unified approach to the quality acceptance testing of RAP base courses. The majority of agencies use field density and moisture content measurements obtained by the nuclear density gauge for compaction control of unbound materials (Nazzal,2014).

Nuclear gauge test results are affected by the presence of asphalt binder, and moisture content adjustments are required to obtain representative dry density values. Various implemented options for compaction acceptance criteria include the following:

- ✓ Nuclear gauge providing dry density values adjusted for the presence of binder (gauge moisture correction)
- ✓ Nuclear gauge providing wet density results only
- ✓ Nuclear gauge providing wet density measurements and Speedy moisture tester used for dry density determination
- ✓ Nuclear gauge used with a control strip
- ✓ Specified number of passes of compaction equipment over a specified layer thickness
- ✓ DCP test and a prescribed moisture content
- ✓ No field testing.

The use of a test method based on strength/stiffness, such as DCP, has been found to be a viable alternative to nuclear gauges. The DCP is simple, durable, and economical, and its use requires minimum training and maintenance (Nazzal, 2014). There is a standard specification for its use, ASTM D6951 (ASTM, 2009d), and it

requires no prior calibration. Various correlations have been developed for the DCP, including the resilient modulus and CBR values.



8. CONCLUSION AND RECOMMENDATIONS

8.1. Conclusion

The laboratory studies provide valuable information on the engineering properties of a reclaimed asphalt pavement RAP. The information provides a basis to establish RAP as an accepted as a base or subbase course in roadway construction. the following conclusions were made from the obtained results.

1. It was observed that the RAP materials can be successfully used in granular sub base layer of flexible pavements after blending to match the required grading as per afnor specifications for road sub base materials.
2. It was also observed that the RAP materials in combination to natural aggregate in various proportions can be easily used after blending to match the required grading as per afnor specifications in the base courses of flexible pavements.
3. It is clear from the above investigation results that 30% replacement of natural aggregate can be successfully done in sub base course of flexible pavements, resulting in a savings of construction cost.
4. It is also clear from the above investigation results that 30% replacement of natural aggregate can be successfully done in base course of flexible pavements, resulting in a savings of construction cost also.
5. From the tests carried out in this study we can conclude that the 30% RAP and 70% virgin materials for the sub base and base layers gives us satisfactory results and corresponds to the specification of the road construction afnor.

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6. Above all the problem of disposal of RAP wastes can be easily solved and adverse effect on environment may be avoided by using the RAP materials in flexible pavement construction.

8.2. Recommendations

8.2.1. Laboratory Testing Recommendations

It is recommended that future research evaluate the use of RAP as base or subbase material address the following topics:

- In order to achieve maximum mass stability in the material, additional gradation of RAP meeting recommended specifications should be examined. The investigation should also examine the drainage of the material.
- A field investigation should be conducted on the effects of climatic and temperature changes on the strength and stiffness of RAP.

8.2.2. Field Testing Recommendations

1. Continue research in the possible use of RAP as a road construction material
2. Research RAP mixtures for possible use in high moisture content soil condition
3. Continue research on temperature profiling of RAP
4. Research the visco-elastic properties of RAP with regard to temperature.
5. Develop a more rigid specification to be used statewide to ensure uniform material properties
6. IT is recommended that future RAP field sites incorporate:

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Uniform subbase or subgrade that is carefully compacted and tested prior to construction monitoring well to record the ground water table leachate collection system to determine both surface water and groundwater environmental characteristics.



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