APPLICATION OF RECYCLED AGREGATE IN ROAD CONSTRUCTION

A Report for major project stage II submitted for the partial fulfilment of the requirement for the

DEGREE OF BACHELOR OF TECHNOLOGY
IN
CIVIL ENGINEERING

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DECLARATION

We do hereby declare that the project work entitled " **Application of Waste Materials in Road Construction"** submitted to the Department of Civil Engineering, **C.V. Raman Global University (CGU), Odisha, Bhubaneswar,** in partial fulfilment of the requirements for the award of the degree of **Bachelor Of Technology In Civil Engineering** is a record of original dissertation work done by us, under the guidance of **Dr. MONALISA PATRA, Assistant Professor, Department of Civil Engineering, C.V. Raman Global University (CGU), Odisha, Bhubaneswar**. We further declare that this work has not been submitted elsewhere for the award of any other degree.

DATE: 21-NOVEMBER-2022

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Title of Dissertation: *Application of Recycled Materials in Road Construction*

We the below signed, after checking the dissertation mentioned above and the official record book (s) of the student, hereby state our approval of the dissertation submitted in partial fulfillment of the requirements of the degree of *Bachelor of Technology* in *Civil Engineering* at C V Raman Global University. We are satisfied with the volume, quality, correctness, and originality of the work.

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Yours Sincerely,

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ABSTRACT

Over the last decade, there has been a dramatic increase in the use of recycled materials/by-products as alternative eco-materials in road construction on widely varying estimates. This increase is due to the scarcity and depletion of the natural resources and the need of large material quantities for the construction of pavement layers. Many kinds of recycled materials or by-products are exclusively employed in pavement construction such as reclaimed asphalt pavement, construction and demolition waste, waste rocks, waste glass, iron slag, cement dust, quarry waste, wood sawdust, waste plastic, waste concrete aggregate and others. Undoubtedly, the use of these recycled materials/by-products in road construction has many benefits on the short and long terms. Some of these benefits are minimizing the use of natural resources, saving millions of cubic meters in landfills, reducing carbon dioxide emissions, reducing energy consumption, and constructing sustainable pavements. However, some barriers to adopt such materials in road construction still exist worldwide. Such barriers are that lack of clients' confidence in such materials, lack of specifications and legalization, etc. During this project various laboratory tests were performed to identify the properties of recycled materials.

1.1 OBJECTIVES

The overall objectives of this report are as follows:

- Investigation of waste materials or byproduct or recycled materials.
- To test various properties of materials in the lab to be used for road construction.
- Analysis of the test results to evaluate suitability of recycled materials for road construction.

1.2 GENERAL

In recent years, alternative construction materials have been the subject of consideration in which several studies have considered using solid waste materials as a substitute to the well-known materials. considered using solid waste materials as a substitute to the well-known materials. Waste generated all over the world (solid or liquid wastes) is increasing day by day. Solid waste was estimated to be 2.01billion tonnes in 2016 and is expected to rise up to 3.40 billion tonnes annually by 2050. There are various classifications of solid wastes such as industrial, agricultural and domestic wastes. Most of the industrial wastes such as steel slag, aluminium dross, and waste tyres are very useful and are recyclable. Recycled materials are materials obtained from various methods of transforming used materials into new ones. Recycling materials have been reported to be utilized in different composition in different layers of road structure from the top surfacing layer to the underneath layers. The processing cost, the engineering properties, the evidence that demonstrate the viability of the material and its positive impact on the long-term performance of the road construction works are what characterizes and favours the use of that specific recycled waste material. It is of the essence to properly understand the behaviour of any recycled by-products, and investigate the influence on the proposed inclusion with a 138-2 construction material in order to come with a suitable and viable utilization with regards to type of material and the employed dosage.

1.3 Recycled Materials

The various recycled waste materials that can be adopted for construction, including their prospects and challenges. Some of the recycled waste materials examined are plastic waste, mill tailings, geopolymers, waste glass, rubber tires waste, shingles, construction and demolition wastes (C&D), iron slag, quarry waste, concrete waste, reclaimed asphalt etc. These recycled materials have been accepted globally due to their characteristic properties which made the materials suitable in the construction industry. Below is the list of some of the recycled materials that we collected for our project to find out its strength and various properties to know its suitability for the construction of the road.

Material Collected

- Normal Aggregate
- Quarry Waste
- Waste Glass
- Concrete Waste
- Reclaimed Asphalt
- Iron Slag
- Bitumen
- Waste Plastic

1.3.1 Normal Aggregate

Based on the bulk specific gravity of the aggregates, the classification is made as

- Light Weight Aggregates
- Normal Weight Aggregates
- Heavy Weight Aggregates

These aggregates have a major role in the manufacture of concrete with varied properties. The field application of these aggregates will hence vary based on the properties of the aggregates showed in the concrete made. Normal weight aggregates, used for most concretes, are naturally occurring gravels from land or marine sources, or crushed rocks, for example, limestone, granite or basalt. Lightweight aggregates are artificially produced aggregates of low density, e.g., sintered pulverised fuel ash (e.g., Lytag), expanded clay or shale (e.g., Lica or Liapor), or natural lightweight materials, such as pumice. Heavy weight aggregates are used for concretes with higher than normal densities (e.g. those used for radiation shielding or ballast purposes). Generally, these are naturally occurring dense rocks such as barytes, magnetite and other heavy metallic ores. Alternatively, metal aggregates, e.g., steel or iron shot, may be used.

Material name: Normal Aggregate

Collected From: Tapang, Khordha

1.3.2 Quarry Waste

Quarry activity is a highly unsustainable process as it produces land, water, air and noise pollution. It adversely affects the ecology of surrounding areas and generating tons of waste. It has been estimated that of entire quarrying process, about 30% to 40% of quarry product is unfit for commercial use and is discarded as waste. This waste is either the filled back in quarry pit or disposed of in landfill which has its own drawbacks. Various research has been conducted which show that this waste has potential to be used as road construction material like fine aggregate, concrete, etc.

Material Name: Quarry Waste

Collected From: Tapang, Khordha

1.3.3 Waste Glass

The utilization of recycled glass in road construction applications has been occurring over the past couple of decades. In recent years, the discovery of several economic and environmental benefits could increase the use of recycled glass in road construction, making the evaluation of the engineering properties of glass and aggregate mixes necessary. The uses of recycled glass have varied widely, depending on the specific application. Crushed recycled glass, or cullet, has been used independently, and has also been blended with natural stone construction aggregate at different replacement rates. This research provides an evaluation of the potential use of glass cullet when used in combination with natural base coarse aggregate for roadway construction.

Material Name: Crushed Glass

Collected From: Janla, Khordha

1.3.4 Recycled Concrete Waste

Many studies have demonstrated that recycled concrete aggregates can be used as construction materials. The most common recycling practice for CDW is the production of recycled concrete aggregates (RCA) that can replace natural aggregates in various applications. The lack of RCA quality standards has led most of the countries to fulfil the requirements by investing in more low-grade applications; for instance, producing RCA for road base and filling materials in road construction. A potential high-quality alternative to downcycling (low value application of recycled concrete aggregate is the use of RCA to replace natural aggregate in concrete. The high-quality use of RCA in concrete is cited by various studies as an important contribution toward the closure of construction materials cycles, as it decreases the amount of residual CDW to be managed, increases the economic value of the recycled material and reduces the quantity of natural aggregate used.

Material Name: Recycled Waste Concrete

Collected From: Near NH 16, Janla, Khordha

1.3.5 <u>Reclaimed Asphalt</u>

Reclaimed asphalt pavement (RAP) materials as removed and/or reprocessed pavement materials that contain asphalt and aggregates. RAP materials are either milled or crushed and used for various highway construction activities like subgrade preparation, recycled hot and cold mix asphalt pavements, backfills, etc. RAP materials are generated when asphalt pavements are removed for resurfacing, reconstruction, or accessing buried utilities. After properly crushing and screening, RAP forms a mixture of well-graded and high-quality aggregates coated by asphalt cement. RAP is used as an aggregate substitute for new or recycled asphalt mixes. RAP is used to produce granular base or subbase aggregate. It is crushed, screened, blended with conventional granular aggregate or any reclaimed concrete material. RAP is used for hot mix and cold mix asphalt pavement. When produced in a central RAP processing facility, finished RAP material that is processed to the desired gradation is incorporated as an aggregate substitute to hot mix asphalt paving mixture. Similarly, cold mix asphalt is produced by combining finished RAP material as an aggregate substitute to cold mix asphalt paving mixture.

Material Name: Reclaimed Asphalt

Collected From: Near NH 16, Janla, Khordha

1.3.6 <u>Iron Slag</u>

Iron slag is a by-product obtained from steel industry. It is generated as a residue during the production of iron. Because of the high disposal cost as a waste material and the overall positive features of iron slag, it has been declared a useful road construction material. Successively, it is recycled as an aggregate for the construction of roads, soil stabilization, and base and for the surfacing of flexible pavement. Despite this, a large amount of iron slag generated from steel industries is disposed of in stockpiles to date. Many researchers have investigated the use of iron slag as an aggregate in the design of asphalt concrete for the road construction.

Material Name: Iron Slag

Collected From: NH 16,Near Mahura, Khordha

1.3.7 <u>Bitumen</u>

The primary use of bitumen is in road construction, where it's used as the glue or binder mixed with aggregate particles to create asphalt concrete. It's used in road construction to bring flexibility to pavements and ensure they strongly bind and hold the construction components together and provide a smooth and levelled surface for the moving vehicles. Bitumen is used in road construction due to various properties and advantages it has over other pavement construction materials. Bitumen gains certain unique properties that are inbuilt in it during its manufacture. The bitumen as a raw material in flexible road construction and bitumen as a mix (composing other materials i.e., aggregates/ pozzolans) serves certain advantages, that prompt to use bitumen widely in road construction.

1.3.8 Waste Plastic

Indian Roads Congress has prepared guidelines for the Use of Waste Plastic in Hot Bituminous Mixes (Dry Process) in Wearing Courses (IRC: SP:98-2013). As per Guidelines: Waste plastic should conform to size passing 2.36 mm sieve and retained on 600-micron sieve. Dust and other impurities shall not be more than 1%. Plastic is coated over stones improving surface property of aggregates. Waste plastic should be 6% to 8% of the weight of bitumen in the mix depending on the climatic condition of high or low rainfall areas. Plastic waste material should consist of only Low-Density Polyethylene (LDPE) or High-Density Polyethylene (HDPE). Black coloured plastic waste is a result of repeated recycling and shall not be used. PVC shall not be used since they release lethal levels of dioxins. The Thermal Gravimetric Analysis (TGA) of thermoplastics reveals gas evaluation and thermal degradation beyond 1800C. Thus, misuse or wrong implementation of this technology may result in release of harmful gases, premature degradation, if the temperatures are not maintained during construction. Size and thickness of plastic waste needs to be maintained. The aggregate mix is heated to 150-1750C in a central mixing plant. The plastic waste coated aggregate is mixed with hot bitumen that a temperature of 1500C to 1700C for about 15 seconds. The road laying temperature is between 1300C to 1600C for the waste plastic bituminous mix.

2. Methodology:

We have performed various tests in laboratory to know the suitability of recycled materials we had collected from various resources. Below are the lists of all the experiments performed during this project.

Specific Gravity Test:

Specific Gravity is defined as the ratio of weight of aggregate to the weight to the weight of equal volume of water. Specific gravity test is a measure of strength or quality of the material. Aggregate having low specific gravity are generally weaker than those with high specific gravity.

Impact value Test:

Aggregates Impact Value gives relative measure of resistance of aggregates to sudden shock or impact, which in some aggregates differs from its resistance to slow compression load. Also, it can be defined as the resistance of aggregate to failure by impact load is known as the Impact Value of Aggregate.

Los Angeles Abrasion Test:

Abrasion test is carried out to test the hardness property of aggregates. The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge. Los Angeles abrasion test on aggregates is the measure of aggregate toughness and abrasion resistance such as crushing, degradation and disintegration.

Water Absorption Test:

Water absorption gives an idea on the internal structure of aggregate. Aggregates having more absorption are more porous in nature and are generally considered unsuitable, unless found to be acceptable based on strength, impact and hardness tests. The maritime code BS 6349 specifies that water absorption should not exceed 3%, or 2% in critical conditions such as highly aggressive chloride.

Flakiness and Elongation Test:

The Flakiness Index of aggregates is the percentage by weight of particles whose least dimension (thickness) is less than 0.6 times their mean dimension. The Elongation Index of aggregates is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension.

Softening Point of Bitumen:

Softening point test of bitumen is done to determine the consistency of bitumen. This test shows the temperature at which the bitumen attains certain viscosity. Softening point is defined as the temperature at which bitumen softens beyond some arbitrary softness.

3. Test Performed:

3.1 Specific Gravity:

AIM OF THE EXPERIMENT: To determine Specific Gravity of given aggregate by pycnometer.

APPARATUS REQUIRED:

1) Pycnometer
2) Balance
3) Distilled Water

THEORY:

The specific gravity is defined by **ISI** as the ratio of the mass of a given volume of the aggregate to the mass of an equal volume of water, the temperature of both being specified at 27°C±0.1°C.

PROCEDURE:

1. The clean, dried Pycnometer is weighted. Let that be W_1gm.
2. Then it is filled with fresh distilled water maintaining temp 27°C±0.1°C for half an hour.
3. The bottle is then filled with distilled water and weighed. Let this be W_2gm.
4. Then the Pycnometer is emptied and cleaned. The given aggregate is poured to one third the bottle, Then it is weighted. Let this be W_3gm.
5. The remaining space in Pycnometer is filled with distilled water at 27°C and is weighted. Let this be W_4gm.

OBSERVATION AND CALCULATION:

The specific gravity of aggregate is given by the formula,

$$G = \frac{(W_3 - W_1)}{(W_2 - W_1) - (W_4 - W_3)}$$

Where W_1 = Mass of clean and dried Pycnometer

W_2 = Mass of Pycnometer with distilled water

W_3 = Mass of Pycnometer with aggregate

W_4 = Mass of Pycnometer with aggregate and distilled water

Tabulation:

MATERIAL NAME	Result 1	Result 2	Result 3	Average
Normal Aggregate	2.78	2.66	2.71	2.72
Quarry Waste	2.87	2.79	2.75	2.80
Waste Glass	2.68	2.62	2.75	2.68
Concrete waste	1.01	1.09	1.10	1.06
Reclaimed Asphalt	2.46	2.47	2.57	2.50
Iron Slag	3.39	3.46	3.40	3.40
Bituminous	1.03	1.09	1.05	1.05

Specific gravity using Pycnometer

Specific Gravity using Density Bottle

3.2 Impact Value:

AIM OF THE EXPERIMENT: To determine the aggregate Impact value of a given aggregate.

APPARATUS REQUIRED:

- Impact Testing Machine:
  (The machine consists of a metal base. A detachable cylindrical steel cup of internal diameter 10.2cm and depth 5cm. A metal hammer of weight between 13.5 to 14kg, 10cm in diameter and 5cm long. An arrangement for raising the hammer allow it to fall freely between vertical guides from a height of 38cm on the test sample in the cup.)
- Cylindrical measure
- Tamping Rod of circular cross section, 1cm in diameter and 23cm long, rounded at one end.
- IS Sieve with 125mm,10mm,2.36mm
- Weighing balance of capacity 500gm to weight accurate up to 0.01gm

THEORY:

Toughness is the property of a material to easiest impact. Due to moving loads the aggregates are subjected to pounding action or impact and there is possibility of stones breaking into smaller pieces. Therefore, a test designed to evaluate the toughness of stones i.e. the resistance of the stones to fracture under repeated impacts may be called impact test on aggregates. The test can also be carried on cylindrical stone specimen known as Page Impact test.

The aggregate impact value indicates a relative measure of the resistance of aggregate to a sudden shock or an impact, which in some aggregates differs from its resistance to a slope compressive load in crushing test. A modified impact test is also often carried out in the case of soft aggregates to find the wet impact value after soaking the test sample.

PROCEDURE:

1. The test sample consists of aggregates passing 12.5mm sieve and retained on 10mm sieve and dried in an oven for 4hours at a temperature of 100°C to 110°C.
2. The aggregates are filled upto about 1/3 full in the cylindrical measure and tamped 25 times with rounded end of the tamping rod.
3. The rest of the cylindrical measure is filled by two layers and each layer being tamped 25 times.
4. The overflow aggregates in cylindrically measure is cut off by tamping rod using a straight edge.
5. Then the entire aggregate sample in a cylindrical mould is weighed nearing to 0.01gm.
6. The aggregates from the cylindrical measure are carefully transferred into the cup which is firmly fixed in position on the base plate of machine in three layers. Each layer is tamped 25times.
7. The hammer is raised until its lower face is 38cm above the upper surface of aggregates in the cup and allowed to fall freely on the aggregates. The test sample is subjected to a total of 15 such blows each being delivered at an interval of not less than one second. The crushed aggregate is then removed from the cup and the whole of it is sieved on 2.36mm sieve until no significant amount passes. The fraction passing the sieve is weighed accurate to 0.1gm. Repeat the above steps with other fresh sample.

Let the original weight of the oven dry sample be $w_1$gm and the weight of fraction passing 2.36mm I.S. sieve be $w_2$gm. Then aggregate impact value is expressed as the % of fines formed in terms of the total weight of the sample.

$$Aggregate\ \text{Impact value} = \frac{100 \times\ \mathrm{w}_2}{\mathrm{w}_1}\%$$

Aggregate Impact value	**Classification**
<10%	Exceptionally Strong
10-20%	Strong
20-30%	Satisfactory for road surfacing
>30%	Weak for road surfacing

TABULATION:

MATERIAL NAME	Result 1	Result 2	Result 3	Average
Normal Aggregate	14.45	16.76	16.02	14.45
Concrete waste	30.32	28.42	29.71	29.48
Reclaimed Asphalt	14.06	16.91	14.00	15.01
Iron Slag	9.11	8.22	9.58	8.97

3.3 Abrasion Test:

AIM OF THE EXPERIMENT: To determine the abrasion value of given aggregate sample by conducting Los Angeles abrasion Test.

APPARATUS:

1. Los Angeles machine with inside diameter 70cm and inside length of 50 cm. Abrasive charges.
2. Set of I.S. Sieve.
3. Weighing Balance of 0.1 gm accuracy.

THEORY:

Abrasion is a measure of resistance to wear or hardness. It is an essentially property for road aggregates especially when in wearing coarse. Due to the movement of traffic, the road stones used in the surfacing to course are subjected to wearing actions at the top. When traffic moves on the road the soil particle (sand) which comes between the wheel and road surface causes abrasion on the road stone. The abrasion test on aggregate is found as per **IS-2386 part IV.** Abrasion test on aggregates is generally carried out by any one of the following methods: -

1. Los Angeles abrasion test.
2. Deval abrasion test.
3. Dory abrasion test.

Los Angeles abrasion test:

The principle of Los Angeles abrasion test is to find the percentage wear due to the relative rubbing action between the aggregate and steel balls used as abrasive charge pounding action of these balls also exist while conducting the test. Maximum Allowable Los Angeles abrasion Values of Aggregates in Different types of pavement layers as per Indian Road Congress (IRC) are:-

For sub-base course a value of 60%. For base course such as WBM. Bituminous Macadam (B.M), Built-Up spray grout base course and etc. value of 50 %.

- For surface course such as WBM, BM, Bituminous Penetration Macadam, Built-Up spray grout base course and etc, a value of 40%.

- If aggregates are used in surface course as bituminous carpet, bituminous surface dressing, single or two coats, cement concrete surface coarse etc. the abrasion value should be less than 35%.
- If aggregates are used for Bituminous concrete, Cement concrete pavement as surface coarse than maximum aggregate abrasion value should be 30%.

Procedure:

1. Clean and dry aggregate sample confirming to one of the grading A to G is used for the test.
2. Aggregate weighing 5 kg for grading A, B, C or D and 10kg for grading E, F or G may be taken as test specimen and placed in the cylinder.
3. The abrasive charge is also chosen in accordance with table no 1 and placed in the cylinder of the machine, and cover is fixed to make dust tight.
4. The machine is rooted at a speed of 30 to 33 revaluations per minute.
5. The machine is rotated for 500 revolutions for grading A, B, C and D for grading E, F and G, it shall be rotated for 1000 revolutions.
6. After the desired number of revolutions, the machine is stopped and the material is discharged from the machine taking care to take out entire stone dust.
7. Using a sieve of size larger than 1.70mm I.S sieve, the material is first separated into two parts and the finer positions is taken out and further on a 1.7mm I.S sieve.
8. Let the original weight of aggregate be W_1 gm and the weight of aggregate retained on 1.70 mm I.S sieve after the test be W_2 gm.

Grading	Weight in grams of each test sample in the size range .mm (Passing and retained on Square hotes										Abrasive Charge	
	80-63	63-50	50-40	40-25	25-20	20-12.5	12.5-10	10-6.3	6.3-4.75	4.75-2.36	No of Spheres	Weight of charge.g
A	-	-	-	1250	1250	1250	1250	-	-	-	12	5000±25
B	-	-	-	-	-	2500	2500	-	-	-	11	4384±25
C	-	-	-	-	-	-	-	2500	2500	-	8	3330±25
D	-	-	-	-	-	-	-	-	-	5000	6	2500±15
E	2500	2500	5000	-	-	-	-	-	-	-	12	5000±25
F	-	-	5000	5000	-	-	-	-	-	-	12	5000±25
G	-	-	-	5000	5000	-	-	-	-	-	12	5000±25

SL NO.	TYPES OF PAVEMENTS	MAX. PERMISSIBLE ABRASION VALUE IN %
1	WBM sub base course	60
2	WBM with bituminous surfacing	50
3	Bituminous bound macadam	50
4	WBM surfacing course	40
5	Bituminous penetration macadam	40
6	Bituminous surface dressing, cement concrete surface course	35
7	Bituminous concrete surface course	30

TABULATION:

MATERIAL NAME	Result 1	Result 2	Result 3	Average
Normal Aggregate	29	28.64	28.76	28.80
Concrete waste	29.2	29.3	29.2	29.23

3.4 Water Absorption Test:

AIM OF THE EXPERIMENT: To determine Water absorption of given coarse aggregate.

APPARATUS REQUIRED:

1) Balance
2) Hot air Oven
3) Container

PROCEDURE

1. The coarse aggregate passing through IS 10mm sieve is taken about 200gm.
2. They are dried in an oven at a temperature of 110°±5°C for 24 hours.
3. The coarse aggregate is cooled to room temperature.
4. Its weight is taken as (w_1 g).
5. The dried coarse aggregate is immersed in clean water at a temperature 27° ±2°C for 24 hours.
6. The coarse aggregate is removed from water and wiped out of traces of water with a cloth.
7. Within three minutes from the removal of water, the weight of coarse aggregate W_2 is found out.
8. The above procedure is repeated for various samples.

TABULATION

MATERIAL NAME	Result 1	Result 2	Result 3	Average
Normal Aggregate	0.65	0.45	0.50	0.53
Quarry Waste	2.5	1.75	1.73	2.13
Concrete waste	4.08	2.01	3.03	3.04

3.5 <u>Softening Point of Bitumen</u>

AIM OF THE EXPERIMENT: To determine the softening point of the given Bitumen by Ring and Ball apparatus.

APPARATUS REQUIRED:

1) Ring and Ball Apparatus containing steel balls each of 9.5mm and weight of 2.5±0.08gm.

2) Thermometer

THEORY:

Bitumen does not suddenly change from solid to liquid state, but as the temp increase, it gradually becomes soften until it flows rapidly. The softening point of bitumen is the temp at which the substance attains particular degree of softening under specified condition of test.

PROCEDURE:

1. Sample material is heated to temp between 75° and 100°C above the approximate softening point until it is completely fluid and is poured in heated rings placed on the metal plate.
2. After cooling the rings in air for 30min, the excess bitumen is trimmed and rings are placed in the support.
3. At this time the temperature of distilled water is kept at 5°C. This temperature is maintained for 15minutes after which the balls are placed in position.
4. Then the temperature of water is raised at uniform rate of 5°C per minute with a controlled heating unit, until the bitumen softens and touches the bottom plate by sinking of balls. At least two observations are made. For material whose softening point is above 80°C, glycerin is used for heating medium and the starting temperature is 35°C instead of 5°C.
5. The temperature at the instant when each of the ball and sample touches the bottom plate of support is recorded as softening point.

TABULATION:

Test Property	Trial
Temp at which I ball touches the bottom plate (celsius)	53.4
Temp at which II ball touches the bottom plate(celsius)	53.7
Final Softening Point Temp.	53.5

3.6 Flakiness and Elongation Test:

AIM OF THE EXPERIMENT: To determine the Elongation Index And Flakiness index of the given aggregate sample.

APPARATUS REQUIRED:

1) Length gauge
2) IS Sieve (100mm, 80mm, 63mm, 20mm, 10mm)
3) A balance of accuracy up to 0.01gm

THEORY:

The elongation index of an aggregate is the percentage by weight of particles whose greatest dimensions (length) is greater than 1.8 times their mean dimensions. The elongation test is not applicable to sizes smaller than 6.3mm. Aggregates which are elongated are detrimental to higher workability and stability of mixes. They are not conducted to good interlocking and hence the mixes with an excess of such particles are difficult to compact to the required degree. For base coarse and construction of bituminous and cement concrete type, the presence of elongated particles is considered undesirable as they may cause inherent weakness with probabilities of breaking down under heavy loads. However, elongation test is conducted on coarse aggregates to assess the shape of aggregates.

The Flakiness index of aggregates is the percentage by particles whose least dimension (thickness) is less than $3/5^{th}$ (0.6) of their mean dimension. The Flakiness test is not applicable to sizes smaller than 6.3mm. Aggregates which are Flaky are detrimental to higher workability and stability of mixes. They are not conducted to good interlocking and hence the mixes with an excess of such particles are difficult to compact to the required degree. For base coarse and construction of bituminous and cement concrete type, the presence of Flaky particles is considered undesirable as they may cause inherent weakness with probabilities of breaking down under heavy loads. However, Flakiness test is conducted on coarse aggregates to assess the shape of aggregates.

PROCEDURE:

Elongation Index:

1. The sample is sieved through IS sieve specified in the table. A minimum of 200 aggregate pieces of each fraction is taken and weighted.
2. Each fraction is then gauged individually for length in a length gauge. The gauge length is used should be those specified in the table for appropriate material.
3. The piece of aggregate from each fraction tested which could not pass through the specified gauge length with its long side are elongated particle and they are collected separately to find the total weight of aggregate retained on the length gauge from each fraction.
4. The total amount of elongated material retained by the length gauge is weighted to an accurate of at least 0.1% of the weight of the test sample.

Flakiness Index:

1. The sample is sieved through the sieves mentioned in the table.
2. A minimum of 200 pieces of each fraction is taken and weighted.
3. In order to separate flaky materials, each fraction is then gauged for thickness-on-thickness gauge, or in bulk on sieve having elongated slots as specified in the table.
4. Then the number of flaky materials passing the gauge is weighed to an accuracy of at least 0.1% of test sample.

TABULATION:

Flakiness Index

Passing through I.S Sieve (mm)	Retained on I.S Sieve (mm)	Wt. of fraction consisting of at least 200 pieces (gm)	Wt. of aggregate in each fraction passing on thickness gauge (gm)
25	20	3160	746
20	16	2010	312
16	12.5	1030	233
12.5	10	554	134
		W = 6754 gm	**W = 1425 gm**

Elongation Index

Passing through I.S Sieve (mm)	Retained on I.S Sieve (mm)	Wt. of fraction consisting of at least 200 pieces (gm)	Wt. of aggregate in each fraction retained on length gauge (gm)
25	20	3160	627
20	16	2010	120
16	12.5	1030	336
12.5	10	554	55
		W = 6754 gm	**W = 1138 gm**

4. LITERATURE REVIEW

4.1 Physical properties & shear strength responses of recycled & demolition Materials in unbound pavement base/subbase

According to Arul Arulrajah et al. Construction and Demolition (C&D) materials, generated by various construction and demolition activities are normally referred to as solid wastes. Construction waste is defined as solid wastes from the construction, remodelling and repairing of individual residences, commercial buildings, and other civil engineering structures. Demolition wastes are generally defined as the wastes from demolished buildings and roads. The traditional method of managing C&D waste materials has been by disposal into landfill. However, recycling and reuse of C&D materials has become a topic of global concern and in recent decades, it has been recognized that C&D and other waste materials volumes are increasing annually and account for a large proportion of waste materials present in landfills. Various researchers have evaluated the sustainability of C&D waste materials in various civil engineering applications such as pavement, ground improvement, pipe-bedding and concrete application. With the increasing use of coarse granular recycled C&D materials in civil engineering applications, a thorough understanding of their shear strength characteristics is required to enable their usage in these engineering applications. This paper investigates the physical and shear strength characteristics of six common C&D materials and assesses the viability of using these C&D materials in pavement base/subbase applications. The six recycled C&D materials studied were recycled concrete aggregate (RCA), crushed brick (CB), reclaimed asphalt pavement (RAP), waste excavation rock (WR), fine recycled glass (FRG) and medium recycled glass (MRG). The physical and shear strength characteristics of the recycled C&D materials were obtained from several test methods being gradation, compaction, Los Angeles (LA) Abrasion, California Bearing Ratio (CBR) and Unconfined Compression Strength (UCS) tests. The shear strength parameters for two modes of failures, direct shear and compression, were also investigated using Direct Shear Test (DST) and Consolidated Drained (CD) triaxial tests. In order for C&D materials to be used in pavement base/subbase applications, the C&D materials must meet local road authority requirements based on these basic and advanced tests in order to ensure the physical and shear strength properties are equivalent to that of traditional quarry materials. The shear strength and durability properties are typically assessed from CBR, LA, UCS, DST and CD tests. The failure envelopes in terms of total stress from DST results and in terms of effective stress from CD triaxial test results are presented in this paper. In practice, the DST on the compacted samples at Optimum Water Content (OWC) is generally performed and the obtained total strength parameters are used for geotechnical design due to its simplicity and low cost even though the samples are in not fully saturated state. Triaxial test on compacted samples in fully saturated state is more complicated but the shear strength parameters obtained is more conservative for design purpose as matric suction does not play a role in shear strength of aggregates. The details of the material tested, testing method, apparatus and results are presented in this paper. The shear responses and shear strength parameters of the recycled materials are then analysed and discussed. This paper is expected to provide a contribution to various parties interested in the usage of recycled C&D materials, inclusive of end-users, designers, contractors and consultants alike as these properties are fundamental in the design and construction of various engineering applications.

4.2 Statistical analysis of recycled aggregates derived from different source for subbase applications

According to A. Barbudo et. al a comprehensive study of the characteristics and behaviour of recycled aggregates with a higher content of masonry cannot be found in the literature. It would therefore be very interesting to estimate the mechanical behaviour of recycled aggregate applied in roads using a fast and easy testing methodology, which could be performed in situ at the treatment plant. The proposed research aims to determine if the composition test, according to EN 933-11, can predict the mechanical behaviour of recycled aggregate (Los Angeles, Proctor Modified, and C.B.R.) using a correlation model. 31 materials were studied in this work. They included natural aggregates and recycled aggregates sourced from crushed concrete, either mixed or not mixed with ceramic materials. The study aimed to characterise their properties, such as water absorption, density, composition, particle size distribution, and the amount of soluble sulphates. Furthermore, other properties that define material performance, such as compaction using the Modified Proctor test, bearing capacity using the C.B.R. test and resistance to fragmentation using the Los Angeles test, were tested. These obtained data were subjected to statistical analysis to ascertain whether or not there are correlations between these properties. Therefore, analysis of variance (ANOVA) was applied to the obtained results, and an analysis comprising simple and multiple correlation was performed. In the same way, the presence of a canonical correlation [19] was sought between the composition of the recycled aggregates and the properties defining their mechanical behaviour. This fact would make possible to estimate the behaviour of different types of recycled aggregates based on their different compositions, without performing these tests of mechanical behaviour. In order for recycled aggregates to be used in road sub-bases, it is necessary for the correct selection of the origin of the materials or treatment in a plant with pre-screening and double crushing. From the obtained correlation, it is deduced that recycled aggregates with less than 25% of masonry can be used in road sub-base. Furthermore, mixed recycled aggregates and ceramics have a good mechanical performance for use in low traffic roads, especially because they have a high bearing capacity, as measured by the C.B.R. index.

4.3 The use of quarry waste in pavement construction

According to Lilian Ribeiro de Rezende et. al the selected material is a waste generated by a cement quarry, called Pedreira Contagem, and located near Sobradinho, a satellite city of Brasilia (capital of Brazil). This material was firstly tested in a laboratory and then its field performance was evaluated by 'in situ' tests. Compaction and California Bearing Ratio (CBR) properties were obtained and analysed by Rezende (1999) and other laboratory properties including resilient modulus, were previously reported by Vale (1999). During the field test, an experimental road-segment with 80 m of length was built on a highway close to the cement quarry (DF-205 West). This highway is classified as a low-volume road with the standard axle operation number (N) equal to 7.6/105. After that, 'in situ' tests such as field CBR, Dynamic Cone Penetration (DCP), plate loading, Pencel pressure meter, Benkelman beam and Falling Weight Deflectometer (FWD) test where performed to analyse the pavement structural behaviour. The pavement structure encompasses a subgrade, a 20 cm thick base layer and a double surface treatment, that is 3 cm thick with chip seal. During construction of the base layer using the quarry waste material, particles larger than 10 cm were removed before water mixing and compaction. It can be noticed that the quarry waste material presents similar resilient behaviour to water contents less than 7.4%, although the CBR values are quite different. These results lead to the conclusion that quarry waste material can successfully replace the natural material used for the base layer, in terms of deformability behaviour. From the laboratory test results, one can notice the general trend of the quarry waste material by analyzing how the strength (CBR) and deformability parameters change due to material status, in terms of water content and dry unit weight.

4.4 Evaluate strength of cement treated recycled construction & demolition aggregates as pavement material

According to V. Gobieanandh et. al this study presents a laboratory investigation aimed to characterize the behaviour of recycled C&D aggregate compared with natural aggregate for road applications. Four samples were prepared by mixing C&D and CA by weight as shown in Table 1. The objective of preparation of different samples is to determine the best mix ratio of recycled C&D and CA to be used as unbound pavement material. Prepared samples were tested in particle size distribution and proctor compaction test to examine their material gradation and moisturedensity relationship respectively. Then the load bearing capacity of the samples were tested with California bearing capacity test. The first part of the research study was the strength characterization of the samples shown in Table 1 to determine the optimum mixing ratio. The second part is dedicated for the performance of cement treated C&D aggregate with CA to determine the optimum mixing ratio for a cement bound pavement which can bear heavy loads. Proctor compaction test and CBR tests were conducted on another 4 samples which were prepared by adding 5% of Portland cement by weight as shown in Table 2. Samples used in test were divided into smaller convenient quantities using Cone & Quartering method and experiments were conducted following British Standard 1377. This paper presents the results of classification test of different aggregate samples which were subjected to particle size distribution and proctor compaction test since C&D waste is highly heterogeneous and consists of different amount of impurities and their quantities are not consistent. California Bearing Ratio (CBR) was checked for relative measure of strength of aggregates for standard 4 day soaked condition. All results were compared with those of the ICTAD road material used in Sri Lankan base layer. Further CBR test were done on cement treated CA-0/C&D-100 sample varying the curing period as 1 day, 4 days, 1 week & 2 weeks, to check initial strength gaining and strength behaviour with time in as a compacted unbound pavement material.

4.5 Influence of the use of recycled concrete aggregates from different sources on structural concrete

According to D. Pedro et. al the properties of the recycled concrete aggregates (RCA) and the effects of their incorporation in concrete have drawn the attention of various researchers. Despite the obvious environmental advantages, this material has distinct properties from those of natural aggregates (NA) that have hindered their regular use. In physical terms, the main difference between RCA and NA is the mortar adhered to the surface of the original NA in the RCA, which is one of the main reasons for the losses of quality of the RCA relative to the NA. The literature shows that even for good quality SC's the incorporation of RA necessarily leads to a greater need of mixing water, i.e., an increase of the w/c ratio to maintain the workability. Therefore, some researchers resorted to superplasticizers to keep the water content within acceptable limits. In order to improve the workability of RAC, Poon et al. suggested changing the humidity conditions in which the RA are kept. When RA kept outdoors were used as replacement of NA, the fresh concrete workability and the hardened concrete compressive strength were only slightly changed when compared with those of the RC. However, when the RA's were used in oven dried or saturated surface dry conditions (extreme cases), the workability and compressive strength were more affected. These results agree with those of Ferreira et al., where the influence of the pre-saturation of CRCA was compared with that of the mixing water compensation method. By analysing the evolution of the water absorption of the CRCA over time, it was found that 70% of its potential value was reached in the first minute and 90% after 5 min. The authors concluded also that the pre-saturation of the CRCA was slightly detrimental to the concrete mechanical performance and especially the durability performance, by comparison with the mixing water compensation method. This paper intends to find explanations for the significant range of values registered. It is believed that this is due to the influence and variability of the SC's from which the RA are obtained. For this purpose, an extensive experimental campaign was developed, including, among others, water absorption by immersion, carbonation resistance and shrinkage tests, which had not been performed so far within the SC influence context. Furthermore, this research intends to complete the evaluation matrix of Gonzalez and Etxeberria, i.e., evaluate in mechanical and durability terms concrete mixes with the target strength as the SC's from the RA used. Except for one family, these authors only evaluate high-strength mixes using low-strength RA.

4.6 Laboratory evaluation of recycled construction & demolition waste for pavements

According to Fabiana da Conceicao Leite et al. studied the possibility of using crushed concrete and demolition debris as sub-base coarse aggregate. CBR experiments were conducted and the behavior of the recycled materials was compared with the behavior of limestone. The results showed that CBR of crushed concrete was similar to that of natural aggregate. Conversely, demolition debris presented a fairly decrease in its CBR. They also analysed the performance of recycled concrete aggregate in base and sub-base applications. The authors concluded that a blended mixture of 25% of recycled concrete aggregate with 75% of natural aggregate would obtain the same resilient response and permanent deformation properties as a dense-graded aggregate base coarse, currently used in base and sub-base layers. Molenaar and van Niekerk studied the influence of composition, gradation and degree of compaction on mechanical characteristics of crushed concrete and crushed masonry in the Netherlands. The results demonstrated that although the composition and gradation have an influence on the mechanical characteristics of the recycled materials, the degree of compaction is clearly the most important factor. Motta [4] studied the mechanical behavior of RCDW aggregates from São Paulo. The results indicated an increase in the resilient modulus over time. In order to verify the pozzolanic activity of this recycled material, the modified Chapelle test was carried out. The results demonstrated the existence of non-inert cement particles in the RCDW aggregate, which improved the performance of the recycled material. In 2004, the first Brazilian standard procedure about the RCDW aggregate application in pavements was published. This standard proposes the use of this recycled material as base and sub-base layers for low-volume roads and considers the CBR as the main parameter to design.

4.7 Evaluation of CBR characteristics of waste dust from construction debris as pavement material

According to Md Murad Hasan et al. Extensive research relevant to properties and act of recycled materials is not available in the literature. The study on mechanical properties of reused construction waste material is quite easy and flexible process to justify the effectiveness in road construction. Barbudo, et. al., conducted research to focus the possible co-relation between various ingredients of recycled aggregates and their mechanical properties for implementing in pavement construction. In this regard, they studied on 31 types of various aggregate, where four types were natural and another twenty seven types were generated from different eleven treatment plants. Finally the sample were taken into test (C. B. R.), Modified Proctor, Los Angeles coefficient) to find out mechanical properties. Then the result was justified with standard statistical tests ANOVA and linear correlation analysis (both simple and multiple) [3]. On-site recycling of construction debris as the pavement construction material reduces the transportation expenses [12]. Arulrajah, A., et. al., conducted another extensive laboratory analysis of the geotechnical and geo-environmental characteristics, where five construction waste materials were taken into count for research. The Construction and Demolition (C&D) elements checked were recycled concrete aggregate (RCA), crushed brick (CB), waste rock (WR), reclaimed asphalt pavement (RAP), and fine recycled glass (FRG). California bearing ratio (CBR), water absorption, particle size distribution, particle density, compaction, Los Angeles abrasion, flakiness index, and hydraulic conductivity and post compaction sieve analysis tests were included in the assessment of geotechnical. A triaxial test was performed, which revealed the shear strength characteristics of the sample. Drained cohesion value from 41 kPa to 46 kPa and drained friction angle ranging from 49° to 51° were found after performing consolidated drained triaxial tests of reused materials. There are few difficulties still remain to recycle construction and demolition waste (CDW) including shortage of confidence of stakeholders, doubtfulness of environmental favor, distance between waste sites and treatment plant of recycling etc., though recycling is the most efficient way to control CDW. An experiment was conducted to check the technical durability of construction debris as material for pavement layers construction of highway. In this regard, efficiency of pavement composed concrete, ceramic waste aggregate and asphalt mix was checked through field research. A research showed the affects of waste dust on, California bearing ratio (CBR), unconfined compressive strength, liquid limit, shear strength parameters, plastic limit, compaction characteristics, plasticity index, and swelling pressure of an extensive soil. A study on the analysis of quality and strength of the concrete that is produced from recycled waste material from various sources. In this regard, rejected waste material was collected from precast industries and concrete fabricated in laboratory were utilized. Application of recycling construction debris instead of fresh virgin concrete assists to alleviate the landfill pressures and promotes the environment quality.

4.8 Application of recycled aggregates from construction and demolition waste with Portland cement and hydrated lime

Arulrajah et al. argued that RCDW aggregate for use as road base and subbase materials has to be evaluated by a rational approach by determining the resilient modulus and the permanent deformation in laboratory tests. Additionally, according to Leite et al. proper compaction effort is an important issue to be addressed when using RCDW aggregate because this mechanical procedure breaks down part of the particles, depending on their composition and strength, affecting their shape, grain-size distribution, and mechanical properties. Likewise, Molennar and Van Niekerk concluded that the degree of compaction is the main factor affecting the stiffness of RCDW aggregate, such that the higher the compaction effort, the greater the resilient modulus. Furthermore, RCDW aggregate usually undergoes particle breakage in the compaction process, increasing the amount of fines and creating new surfaces. In this context, the material may still contain non-hydrated cement from mortar or recycled concrete aggregates or fine particles from ceramic bricks and tiles. The combination of these materials with water during the compaction process can provide, after curing, a substantial increase in stiffness through the pozzolanic reaction. Although researchers have commonly observed that stiffness increases over time due to pozzolanic reactions by non-hydrated cement and ceramic fines, incorporating additional amounts of hydraulic binders (e.g., hydrated lime or Portland cement) can result in a substantial increase in stiffness. The RCDW aggregate may contain components such as silicates, carbonates as calcite, hydroxides, and quartz. The addition of hydrated lime or cement and water may induce hydration of these components. In the case of adding these binders (hydrated lime and cement), the mechanical behaviour of RCDW aggregate becomes more similar to a cement-treated material rather than a granular one, as observed by [3,16]. For field performance, Agrela et al. evaluated RCDW aggregate mixed with 3% of Portland cement as a pavement subbase layer; pavement deflections were measured using a falling weight deflectometer (FWD) and the results were considered useful as they showed low variability. However, the traffic volume was 200–799 heavy vehicles per day. Herrador et al. comparatively analysed a base layer with recycled aggregate composed of concrete waste, asphalt mix, and ceramic materials and obtained satisfactory deflections results. However, the study does not present a descriptive statistical analysis or the eventual response variability. Furthermore, the pavement test track was built for rural roads, with limited traffic. Tavira et al. analysed road characteristics and recommended applying RCDW as a pavement layer for traffic volumes of 25–49 heavy vehicles/day. Typically, previous studies limited the application of RCDW to rural roads or roads with low traffic volumes; however, they have not applied RCDW to heavy-traffic roads, which directly impacts its potential use at large scales. The application in pavement structures subjected to high and heavy traffic roads may be reckless, due to the inherent variability of this material. However, the addition of hydraulic binders could reduce variability and increase mechanical strength, so the application on a real road with heavy trucks operation could be used with a field verification.

4.9 Construction of road sections using mixed recycled aggregates

According to Francisco Agrela et al. The CRA are in higher demand and can be used in higher value-added applications, as the coarse fraction can be used in the manufacture of structural concrete. many countries have included within their regulations the possibility of partially replacing the coarse fraction of natural aggregate with CRA in percentages ranging between 20 and 50% (BS 8500- 2:2006; EHE, 2008). Another application of CRA is the construction of roads as either bound or unbound granular layers (Molenaar and Van Niekerk, 2002; Xuan et al., 2010). The principal limitation is the acid-soluble sulphate content, with a maximum of 0.8% allowed by Spanish regulations (PG3, 2004). However, most of the RA produced in Spain is MixRA, and they are usually used in the construction of embankments and compacted layers on sub-grades. Some authors have studied the possibility of using these materials in applications with higher added value, such as the construction of untreated granular sub-bases (Vegas et al., 2008; Jiménez et al., 2011). Cement treated granular materials have been used as semirigid base course for road sections. Their mechanical properties have been studied in order to be applied in structural designs (Lim and Zollinger, 2003). There are a few researches on the properties and mechanical behaviour of MixRA treated with cement when used as road sub-bases or bases in actual civil works. Xuan et al. (2011) studied the influence of the proportion of masonry particles in MixRA, and they determine the relationship between the degree of compaction, the cement content and the masonry content in the compressive strength of the cement treated granular materials. The purpose of this study is to assess the behaviour of two MixRA through laboratory testing and with experiment sections and to compare them with a natural aggregate; all aggregates were treated with cement. We studied the properties of two MixRA and a natural aggregate (NA) in the laboratory to prove their feasibility in a real application, as cement-treated aggregates used as a road sub-base. In September 2009, two sections of an access ramp to a motorway located in Malaga, Spain was constructed. Several tests were conducted to evaluate their performance. The results of an investigation into the use of mixed recycled cement-treated aggregates to build the sub-base and base layers of roads. Prior to the performance evaluation, the aggregate properties were first evaluated. Regarding the materials.

4.10 Alternative processing procedures for recycled aggregates in structural concrete

According to Marco Pepe et al. This study is focused on the ‘‘grey’’ fraction with emphasis on the mechanical performance. The homogenisation process was carried out by means of a so-called ‘‘cells process’’ (homogenising process per unit cell), in which the raw materials were distributed on a plastic sheet in different layers throughout the whole length of the sheet. Thus, with this, the raw concrete particles are homogenously distributed over the length of the sheet, and, starting from the middle section, layers of raw materials are subdivided in several sections called ‘‘cells’’. Next, the homogenised material was then grinded with a crusher, jaw crusher type (model Queixada 200 produced by Vegedry). During the grinding phase, the material was separated into two classes, namely fine and coarse aggregates. For each sample of the homogenised material, about 40% was obtained as coarse aggregates (nominal diameter bigger than 4.75 mm) and the rest was defined as fine aggregates (sand). After grinding, the recycled aggregates were sieved and divided into the three size classes already defined before in Section 2.2. With the aim of reducing the amount of fine materials attached to the surface of recycled aggregates (mainly debris from cement paste and sand, called ‘‘attached mortar’’), an autogenous cleaning process was conceived and performed. With this process RCAs are placed in a rotating mill drum and collide against each other while removing pieces of attached mortar. The mill drum, 30 cm in diameter and 50 cm in depth (Fig. 1), was filled up to 33% with ‘‘raw’’ recycled aggregates and the rotation rate was imposed to 60 rotations for minute. After the autogenous cleaning process, aggregates were cleaned with water and subsequently dried to remove all the produced fine remainings and impurities. The efficiency of the autogenous cleaning process was analysed by investigating how it actually modified the key physical properties of the particles after applying different durations of cleaning (ranging from 2 to 15 min). To have a first impression of the cleaning efficiency, some preliminary trials cases were performed on raw RCA particles (i.e., not homogenised). The effect of these trial procedures was ‘‘measured’’ by determining the water absorption capacity of the same particles before and after various ‘cleaning’ durations. The results of autogenous cleaning, for both Brita 0 and Brita 1, showed a progressive decrease of the water absorption capacity, with increasing durations from 2 to 10 or 15 min. Based on these preliminary findings, the final choice for the duration of autogenous cleaning of the homogenised particles used in the experimental program is 10 and 15 min. Within the experimental program, several tests were performed on both natural and recycled aggregate samples while aiming at comparing their key mechanical and physical properties like water absorption, bulk density grain size distribution, thermal treatment for evaluating the attached mortar, image analysis using photographs and 3D CT-scanning analysis.

4.11 Use of recycled aggregates in rigid pavement construction

According to Radu Andrei et al. The research aims to develop the recycling technology of construction and demolition waste (CDW) for obtaining recycled aggregates with physical mechanical characteristics suitable for use in the construction of plain cement concrete pavements (PCC) and roller compacted concrete pavements (RCC). Also, for improvement of the behavior in exploitation stage, steel fiber reinforcement of PCC/RCC with recycled aggregates will be studied. To achieve the proposed objectives laboratory tests will be performed to determine and evaluate both the physical-mechanical characteristics of recycled aggregates and the performance of fresh/hardened road cement concrete made with recycled aggregates. The research is relevant for the social and economic environment from Romania justified by the new legislation on waste, Directive 2008/98/EC, implemented by the European Council to member states. The main objective is to increase, at a minimum of 70% by mass, the reuse and recycling of CDW to minimize the negative effects on the environment and human health (Bâsceanu, 2007). The most important flow for generation of CDW results from demolition of existing buildings, but significant quantities result also from activities like the construction/renovation of buildings or construction/rehabilitation of road and railroad infrastructures. The cement concrete recycling from CDW leads to improvement of environmental pollution parameters by preserving natural resources and generating free space in landfills. Also adequate economical value recovery of the cement concrete will be achieved by producing recycled aggregates which can be used in higher value construction works. The experimental study shows that with minimum effort, appropriate aggregates can be obtained by cement concrete recycling which may compensate the consumption of needed natural crushed aggregates in pavement engineering. The performed laboratory tests have proved that recycled aggregates had similar performance characteristics with crushed gravel as chippings used in rigid pavement construction. The resulted recycled aggregates present a continuous grading curve, an important characteristic for the performance of the cement concrete slabs. Recycled aggregates and natural crushed aggregates can be used concomitant for the construction of cement concrete pavements in different proportions. In literature (Won, 1999) laboratory tests show that if maximum 30% of natural aggregates used in cement concrete manufacturing is replaced with recycled aggregates, the performance characteristics of hardened concrete are not significantly affected. This could be the most simple, economical and less problematic method for using recycled aggregates in concrete manufacturing.

4.12 Use of recycled solid waste materials in asphalt pavements

According to Yue Huang et al. The use of recycled materials in roads varies across the UK (TRL, 2001). This is probably due to the difference in access to suitable natural aggregates and in the capacity of local landfills. Other than technical barriers may exist, as for example, lack of collecting infrastructure, alternative use of recycled SWM, limited market information and additional cost all may inhibit the waste from being recycled into pavement asphalt. The government encourages recycling by legislation, purchasing power and grants that are offered to companies to help initiate recycling locally (QPA, 2004). The use of recycled SWM in asphalt pavements must have a value-added prospect and is likely to be practical where there is a consistent supply. From a technical perspective, asphalt with well crushed glass (e.g. ≤4.75 mm) replacing a few percent (e.g. 10–15%) of fine aggregates should not be excluded from use in asphalt surface layers, as glass particles are ground too finely to present any safety risks, and PSV and AAV requirements apply only to coarse aggregates in the mixtures. However, this may pose a non-technical barrier as fine aggregates are only used in moderate amount in SMA and OGFC, where recycled SWM that can be used in larger size (e.g. steel slag) makes a better choice because of less processing requirements and a higher replacement rate. It is recognised that the replacement rate should be allowed to vary to the size of glass particles, and vice versa (Maupin, 1998). Steel slag should be used in place of coarse aggregates in surface asphalt, to make best use of its mechanical strength and skid resistance. Large particle size and high content are recommended by laboratory and trial results. The main drawback is the high specific gravity of steel slag (3.2–3.6), if used in stone-dominated mixtures like SMA or OGFC, will drive up the overall mix density, implying an increase of transport cost. The presence of free CaO/MgO in slag makes it liable to expand in humid condition and therefore unsuitable for use in structures vulnerable to volumetric expansion. The common approach is to expose the slag to spray water or natural weathering for a period of between 12 and 18 months (Airey et al., 2004; FHWA, 1997). The time span could be reduced if chemical treatment is performed before the slag leaves the steel plant as is the practice in Germany, although the associated cost and environmental implication need to be further investigated. Leaching potential is one of the main environmental concerns over the use of secondary materials in road structures (Mroueh et al., 2001). Research in Germany has identified pH-value, electrical conductivity and Chromium concentration in the leachate as the main concerns for using slag aggregates (Motz and Geiseler, 2001). In general, tyre rubber is used in asphalt mixtures to reduce cracking, improve durability and mitigate noise. Depending on the application, different variables need to be considered when assessing the technical performance of asphalt containing tyre rubber: binder properties in the wet process, and mixture properties in the dry process. So far, most laboratory and field work has been focused on the 'wet' trial. It is generally agreed that asphalt rubber mixtures improves durability and low-temperature performance. On high-temperature performance however, there are mixed views in the United States ranging from better, similar or comparable, to worse. Results from the 'dry' trial so far are of limited number, and are as well far from conclusive. Generally, rubberised asphalt does not show significantly improved performance to offset the additional cost (FHWA, 1997; Oregon DOT, 2002). The wet process is more tolerant, whilst the dry process requires extra care in materials selection, mix design and asphalt manufacture. The economic breakeven point in both processes is whether the increased cost (e.g. waste processing, higher binder usage) can be warranted by a return through longer pavement life.

4.13 Application of cement-treated recycled materials in the construction of a section of road

According to Pablo Perez et al. The re-use of these wastes provides a great environmental benefit because they are recycled and, consequently, the exploitation of quarries and gravel pits in the natural environment is reduced. These RCA materials have been investigated for the production of structural concrete, non-structural concrete and sub-base materials for roads, either as unbound material or cement treated granular material. These RCA are most frequently used in road bases and sub-bases. Poon and Chan investigated the load-bearing and compression capacity of both RCA and a mixture of this RCA with bricks for their use in the road sub-bases. The feasibility of these materials were demonstrated when they present CBR values higher than 30%. Xuan et al. [14] studied the mechanical properties of RCA treated with cement in laboratories. Their research demonstrated that the mechanical properties of the CTGM manufactured with RA depend on the type and content of cement used, as well as the quantity of water, the curing time, and the quality of the RA themselves. Herrador et al. [15] conducted a study on the application of RA from CDW, where two sections of road were constructed and tested, namely, one linking highway A-367 to highway A-357, in the municipal township of Ardales, Málaga (Spain). The use of recycled materials instead of natural materials in sub-base layers, in a level below the surface of the pavement, was demonstrated to be a real and appropriate alternative, as both materials exhibited the same characteristics and were equally appropriate. This result implies that the natural aggregates could be progressively substituted with recycled aggregates (CDW). Agrela et al. undertook a project consisting of the application of RMA obtained from a mixture of concrete and masonry work in the elaboration of CTGM. In the project, 100% of the natural material was substituted so that some sections of road were compared. The first and the second sections contained two different types of recycled aggregates and the third one contained natural aggregates. The RMA were demonstrated to have an adequate mechanical capacity, and the road surface presented few deformations two years after its execution. The present project aims at studying the efficiency of using RCA treated with cement in the construction of a road in Málaga, Spain. Some sections of this road were built using recycled CTGM, applying RCA to form a cement treated base layer. The natural coarse aggregate was substituted by coarse fraction of RCA, and natural sand was applied to complete the mixture of recycled CTGM. Furthermore, before using the materials in road execution, their material properties were studied; in addition, auscultation tests were performed in the short and long-term to evaluate the mechanical behaviour of the materials and its evolution over time.

4.14 Impact of wet and dry recycled aggregate in road construction

According to Won Jun Park et al. the application of recycled aggregate has been expanded to major concrete structure elements, such as the columns and beams of construction structures. For concrete, the major material used in the construction industry, environmental impact analysis is required because it discharges many substances with a high environmental load over its life cycle from production to construction, maintenance, and destruction/disposal. Concrete is a mixture of cement, aggregate, and admixture. Cement production consumes a large amount of energy during the processes of extracting limestone and clay and manufacturing clinker. Moreover, soil erosion or ecosystem destruction may occur in the process of collecting the necessary aggregate. Energy is also consumed in the course of transporting materials, such as cement and aggregate, to concrete manufacturers, and when producing concrete in batch plants, various high-environmental-load substances are discharged into the air, water, and soil. As the concrete production process impacts the environment in a variety of ways, it was necessary to assess various environmental impact categories. First, for concrete with a compressive strength of 24 MPa, a life cycle assessment was performed according to the volume fraction (substitution rate) of recycled aggregate (R.G) used instead of natural aggregate. As the volume fraction increased, GWP, one of the environmental impact categories, increased by 11–34% compared to when only using natural aggregate. This is because CO2, CH4, and N2O emissions, which all have a major effect on GWP, are larger during the production of recycled aggregate than during the production of natural aggregate. As the volume fraction of recycled aggregate increased to 10%, 20%, and 30%, the ADP decreased by 9–29% compared to the ADP of the concrete with natural aggregate only. The environmental impact of recycled aggregate (wet) was up to 16%(EP)~40%(AP) higher compared with recycled aggregate (dry); the amount of energy used by impact crushers while producing wet recycled aggregate was the main cause for this result. Comparing the methods of production, while the environmental impact of the recycled aggregate produced by the wet method is somewhat high, the wet method remains the most practical method, and is beneficial in terms of the aggregate quality attained due to the high fine-powder-removal effect achieved by washing with water. The recycled aggregate produced by the dry method has a simpler production process and a lower production cost, but its quality requires improvement because the impurity and adhesive mortar removal efficiency is low. The environmental impact of using recycled aggregate was found to be up to twice as high as that of using natural aggregate, largely due to the greater simplicity of production of natural aggregate requiring less energy. However, ADP was approximately 20 times higher in the use of natural aggregate because doing so depletes natural resources, whereas recycled aggregate is recycled from existing construction waste. Among the life cycle impacts assessment of recycled aggregate, GWP was lower than for artificial light-weight aggregate but greater than for slag aggregate. This is because energy use, such as electricity, LNG, and coal in the mixing, molding, and frit sealing process during the production of artificial light-weight aggregate was higher than the amount of energy used in the production of recycled aggregate. However, in the environmental impact of recycled aggregate, AP, EP, ODP, POCP, and ADP were lower by 37% to 93% than that of artificial light-weight aggregate and slag aggregate. Although the concrete into which recycled aggregate was substituted exhibited a somewhat higher environmental impact than natural aggregate in terms of GWP, it was found to be more environmentally friendly in terms of ADP.

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