Examination of bituminous mixtures made of conventional aggregates and recycled materials

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Bituminous mixtures are usually used as surface or base layers in a pavement structure mainly in order to distribute stresses caused by loadings as well as for the protection of the unbound sub base layers form environmental factors. Mix design, construction phase, properties of mixtures' components and the use of additives have an impact on bituminous paving mixture's properties, Although studies all over the world have been made in understanding the behavior and the factors that affect bituminous mixtures' performance, much work has to be done in the future. Scientists usually focus their research on changes on the properties of mixtures' components but also in the availability of good sources of the two main components, which are bitumen and aggregates, direction which has been followed in present paper. At the same time, the need for sustainable development and environment protection causes the improvement of existing technology and knowhow by further research on alternatives to conventional materials.

Present research paper includes the evaluation of bituminous mixtures made of bitumen 50/70, natural asphaltite, conventional aggregates and RAP (Recycled Asphalt pavement). Four series of bituminous mixtures are produced and examined. Main purpose of the research is to examine and evaluate mixtures with asphaltite and recycled materials (RAP), in order to suggest their use in road construction works by designing and producing of bituminous mixtures that can meet the ever-increasing structural needs of modern pavements.

According to laboratory test results, it can be concluded that the use of RAP improves bituminous mixtures' properties, while inclusion of asphaltite has a slightly positive effect on them. However, both materials provide mixtures with satisfactory characteristics.

Keywords: bituminous mixtures, recycled aggregates, recycled asphalt pavement (RAP), asphaltite, environment

1. Introduction

There are enormous streams of C&D Wastes that are generated annually. Such wastes are old bitumen, old concrete, steel, glass, wood and many other materials which are included in the European Waste Catalogue (No17)[1]. Moreover, looking towards sustainable development, while at the same time reducing extraction of natural resources, many countries through industry are trying to incorporate best practices to help ensure quality of life for generations to come.

On many levels, asphalt production, laying and its many different applications can contribute to sustainability in ways not obvious to the general public. Asphalt is 100% recyclable and can be used in maintenance works as well as for the production of new bituminous mixtures [2]. Simultaneously, inclusion of alternatives to natural aggregates such as Recycled Concrete Aggregates (RCA), Recycled Asphalt Pavement (RAP) etc may lead to new mixtures not only with satisfactory characteristics (physical, mechanical, durability etc) but also to the lowering of fuel consumption and the consequent emission of polluting gases, which have great impact on the environment and quality of life. As a result, this new technology may reduce the quantities of "wastes" as well as help natural resources, such as aggregates and bitumen, efficiency while inserted one of the techniques with a growing potential in the following years [3].

As time passes by, C & D Wastes increase with really high rates annually, most of which are usually illegally deposited. In the USA, 100 million tons of RAP is the result of new construction and maintenance works [4], while quantities generated in Europe in 2012 reached the amount of 383millions tones [5], 50 million tons of which was RAP [6]. Germany, the Netherlands and Sweden are the countries that incorporate the largest percentages of RAP in Europe in the production of new hot and warm mix asphalt, [7]. Those countries have understood well the fact that the recycling of pavement associated with warm mix asphalt can be seen as a sustainable option, as it brings social, environmental and economic benefits. They noticed that the use of warm mix asphalt power brings advantages due to the lower consumption of energy required for their manufacture, thus implying reductions of 30-40% of carbon dioxide emissions (CO_2) and allowing a more comfortable work environment, guaranteed by a 30-50% reduction of the exposure to fumes by workers at bituminous plants and/or by paving teams [8]. The reduction of emissions allows manufacturing plants of warm mix asphalt to be located near to urban areas [9], while the use of RAP prevents the deposition of milled material in landfills, reduces the amount of new aggregates and the extraction of bitumen from the planet. So it is of crucial importance to find ways of evaluating and reuse of those wastes in other countries as well by adopting best practices of existing know how, given that in the near future the C&D W's quantities are expected to increase further due to the fact that many building and construction works reach the end of their life cycle. Moreover, the constantly increased quantity of natural aggregates which are going to be used in private of public works (concrete, road construction…) is against resources efficiency and environmental protection, since those raw materials are natural and therefore limited.

Increase on C&D Wastes' quantity all over the world, in combination with the reduction of quantities of natural resources (aggregates and bitumen) has led to studies aiming at examining the use of alternatives, such as recycled aggregates or "recycled/ modified bitumen" in road construction works. Towards this direction many studies focus on partial or even whole replacement of either bitumen or aggregates in bituminous mixtures by other materials with similar characteristics, while properties examined are physical, mechanical and environmental ones. Bitumen can be modified by wastes such as rubber, while conventional aggregates may be replaced by recycled aggregates or recycled asphalt pavement (RAP), which is a viable solution that allows both reducing waste production and resources consumption. Across Europe, a number of studies have been conducted with the overall objective of stimulating the reuse of RAP, in many cases with RAP contents as much as 60% [10-12]. In these studies, RAP is not seen as a waste, but as a material that carries valuable characteristics and that can preserve conventional aggregates for the next generations.

Many authors have approached the Warm-Mix Recycled Asphalt (WMRA) use, since the production of hot mix asphalt is responsible for a large consumption due to the heating of its components (aggregates and binder). This energy is spent on the burning of fossil fuels and the consequent greenhouse gas emissions [13-21].

Studies, carried out all over the world, aim at the examination of new technologies which may lead to reduction in mixing energies and consequently, the emission of $CO_{2,}$ by examining at the same time basic properties of the produced mixtures as well as to a reduction of the materials quantity doomed to landfills.

Magnoni et al, 2016 [22] published a case study concerning two rehabilitation methods adopted in a reconstruction project of two taxiway pavements in a major airport located in the northern part of Italy. Publication included the entire process of rehabilitation works starting from the preliminary investigations to the final quality controls and the examination of pavement's behavior when recycled aggregates from old concrete slabs were used. Recycled materials have been used in order to reduce conventional aggregates consumption and hauling-related emissions. According to test results, use of recycled aggregates lead to a reduction of raw aggregates in about 0,63m³/m² while a 47% reduction in CO_2 emission has been achieved.

Carvalho and Barreno (2013) claim that reducing the manufacture temperature of bituminous mixtures, it will get economical savings due to a lower fuel consumption that can be between 25 and 35%, depending on the

aggregates type and degree of humidity. On the other hand, they also claim that by reducing the fuel consumption there will be an important reduction of greenhouse emissions. The CO_2 emitted can be reduced between 25 and 40%, contributing to a better climate. The same occurs in the emissions of CO and NOx [23].
To the same environmentally efficient conclusion reached the research of Dinis-Almeida et al, 2016, where addition of RAP up to 100% in warm asphalt mixtures led to reduction of footprint by the reduction of quantities of wastes deposited in the environment without changing the properties of the final mixtures. Mixtures have been produced at lower temperature -between 100 and 140^{o}C (drying)- than traditional hot mixtures due to the use of asphalt emulsion at ambient temperature (generally below 25^{o}C) instead of bitumen. Behavior of mixtures has been studied by means of laboratory tests such as water sensitivity, stiffness, fatigue resistance and rutting resistance. In particular, the Warm Mix Recycled Asphalt (WMRA) overall laboratory performance compared to the conventional Hot Mix Asphalt (HMA) showed better results in terms of water sensitivity, while fatigue resistance was proven to be similar. In terms of rutting resistance, mixture containing 80% RAP and 20% coarse aggregates, was the most stable material [12, 24]. Others mixtures were not that stable, due to the hard bitumen included in RAP, due to aging procedures of the old pavement.
Another research's findings confirmed the advantages and the demonstrated good performance of warm mix asphalt compared to conventional hot mixtures which occupy a preferential place in the road construction. These mixtures have been produced at lower mixing temperatures, while their mechanical performance proved to be comparable with conventional HMA, as far as the stiffness modulus and fatigue resistance is concerned. It should be noted that the mixture produced with RAP did not contain any additive to improve the aged bitumen performance. They presented also a good alternative in the rehabilitation of the road pavements concerning environmental, social and economic aspects [6].
Finally, another research's experimental results conducted by Settari et al, 2015 showed that it is possible to manufacture Roller Compacted Concrete (RCC) with a maximum of 50% of RAP materials, which has several advantages, such as contribution to the resolution of waste storage problem, the reduction of the environmental pollution, the safeguarding of natural resources, the reduction of construction cost and the increase of supply in natural aggregates [25].
Given the indicative existing know how as mentioned above, and taking into account the needs of Greek industry and Greek data on road construction, the necessity for the investigation of alternatives materials for the production of new warm asphalt mixtures is more than obvious. So, present paper is dealing with the examination of the use of RAP and asphaltite for the production of new warm bituminous mixtures, which are a combination of natural and recycled materials. Its scope is to certify the use of those green materials in road construction, since it may reduce both quantities of bitumen and aggregates, leading at the same time in mixtures with satisfactory characteristics.

2. Experimental part

2.1 Materials used

Materials used for the experimental part of current research were bitumen 50/70, natural aggregates, RAP and asphaltite (Selenizza) and have been supplied by Anakyklosis Adranon Voreiou Ellados SA [26]. In particular, bitumen 50-70 originated by Hellenic Petroleum S.A. Fine aggregates of size 0/4mm (sand) as well as coarse ones of size 8/16mm originated by the quarry of Lafarge Beton ABEE in Messaio while coarse ones of size 4/8mm from the quarry of Pavlidis SA in Plagiari Giannitson. Sellenizza®[27] has been supplied by Tsakas Ltd, while RAP originated from road works near the area of Central Macedonia. The design of bituminous mixtures has been based on Greek Specifications and especially bituminous type AC12.5 according to ELOT Technical Specification 1501-05-03-11-04:2009[28]. AC12.5, which's maximum grade size is 12.5mm, is a bituminous mixture of dense/closed type and is used for surface layers due to the finesse of the aggregates used.
The bitumen of *Selenizza* ® is contained in an asphaltite ore substance and is extracted from underground galleries or open pit mines at the deposit of Selenice (Albania). Under this form, it is called natural bitumen and after a refining process, the obtained clean bitumen is known under the trade name of Selenizza®. Asphaltite is used as a modifier of bitumen 50/70, so it is expected to influence bitumen's properties as well as mechanical characteristics of the final bituminous mixture. Selenizza® is usually added during the asphalt mixing process.

Figure 1. Selenizza®

RAP can be produced in two ways: The first one is by the use of special equipment, i.e. bitumen cutter. This can be accomplished either by scraping the asphalt layers to the desired thickness, in order to restore it or by the use of an excavator, which removes big particles of pavement (including subbase/base). Following, bituminous particles are extruded and treated further in order to get it into the desired gradation.

Figure 2. Scraping of old bituminous surface layer [29]

Figure 3. RAP, by the use of an excavator

All of those materials have been tested according to European Specifications in order to certify their use for the production of new bituminous mixtures. Experimental results are showed in tables below (1-4)

Table 1. Characteristics of binder (bitumen 50/70)

A/A	*Test*	*Limits set by EN12591 for bitumen 50/70*	*Result*	*Specification for testing*
1	Penetration at 25^{o}C (0,1mm)	50-70	61	EN1426
2	Softening point (^{o}C)	46-54	49,7	EN1427

Table 2. Characteristics of conventional aggregates

A/A	*Test*	*Limits set by ELOT TG 1501-05-03-11-04:2009*	*Result*	*Specification for testing*
1	Gradation curve	-	See Figure 4	EN933-1
2	Los Angeles test	≤30	26	EN1097-2
3	Water absorption (%) (size 0-4mm/4-8mm/8-16mm)	-	0.13/0.20/0.32	EN1097-6
4	Particle density (Mg/m^3) (size 0-4mm/4-8mm/8-16mm)	-	2.69/2.71/2.70	EN1097-6
5	Sand equivalent (%)	≥55	71	EN933-8
6	Methylene blue (gr/kg)	≤10	0.5	EN933-9
7	Flakiness index 4-8mm/8-16mm (FI) (%)	≤25	10/15.9	EN933-3
8	Weathering property-magnesium sulfate test (%) (size 0-4mm/4-8mm/8-16mm)	≤18	2.5/2/2.5	EN1367-2

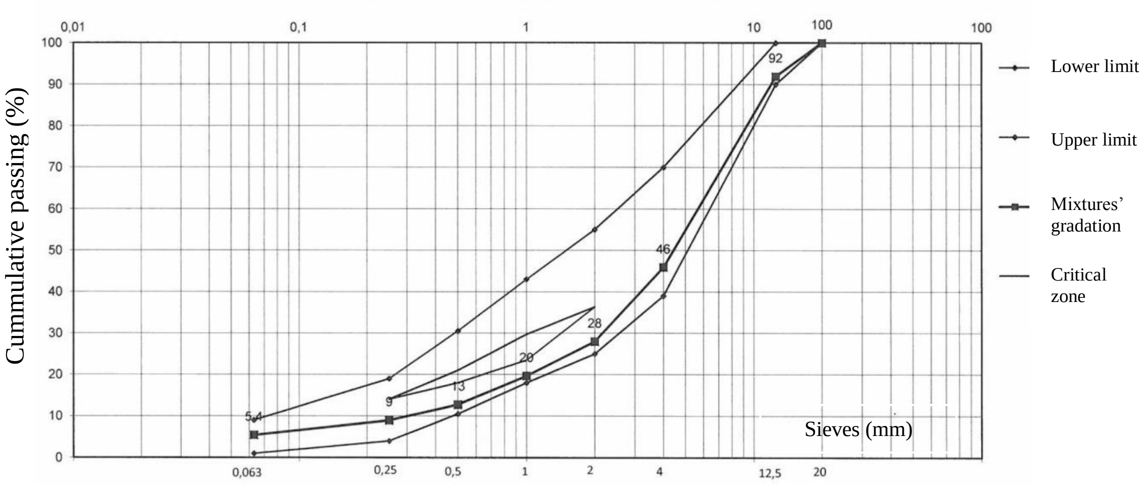

Figure 4. Gradation curve of aggregates

Table 3. Characteristics of a*sphaltite* (Selenizza)

A/A	*Test*	*Result*	*Specification*
1	Penetration at 25°C (0,1mm)	0	EN1426
2	Softening point (°C)	120	EN1427
3	Mass loss at 163°C, 5hours (%)	0.08	EN13303

Table 4. Characteristics of *Recycled Asphalt Pavement (RAP)*

Water absorption	WA_{24}	1,60%

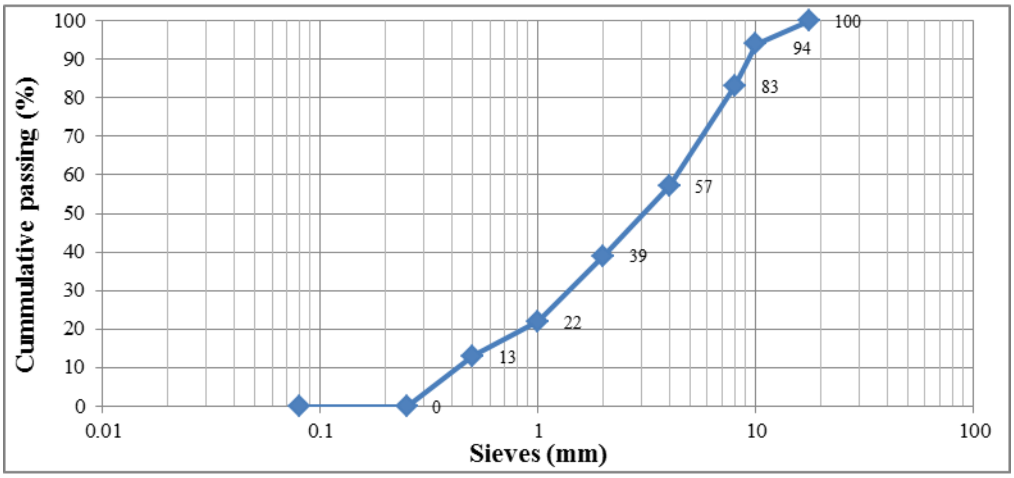

Figure 5. Gradation curve of RAP

Quantities of materials used per ton of the four series of bituminous mixtures produced and examined are as showed on Table 5.

Table 5. Compositions

A/A	*Composites*	*Percentage (%)*	*Quantity (kg/tn)*
1	Bitumen 50/70	4.50	45.00
	Natural aggregates	95.50	955.00
2	Bitumen 50/70	4.50	45.00
	Asphaltite (12% w/t of bitumen 50/70)	0.54	5.40
	Natural aggregates	95.50	955.00
3	Bitumen 50/70	3.30	33.00
	Natural aggregates	67.69	676.90
	RAP (30% w/t of aggregates)	29.01	290.10
4	Bitumen 50/70	3.30	33.00
	Asphaltite (12% w/t of bitumen 50/70)	0.40	0.13
	Natural aggregates	67.69	676.90
	RAP (30% w/t of aggregates)	29.01	290.10

2.2 **Production of warm asphalt mixtures/unit**

The asphalt plant, where all compositions have been produced, is fully licensed and is one of the most modern plants. It is located in the industrial area of Sindos Thessaloniki in zone C, in three contiguous plots, covering a total area of 25.082 m^2. The unit has a capacity of 350t/h and consists of the following sections:

Supplier of aggregates: The unit has six (6) aggregate supply straps and a belt collection of six (6) feeders . The amount of aggregates entering the feeders and the quantity delivered to the collection belt is monitored by the electronic system of the unit, enabling the operator to perform precise recipe for each composition.
Supplier of RAP: RAP is supplied by two (2) specific feeders of maximum capacity of 60t /h.

Figure 6. Supply of aggregates and RAP

Drying oven (oven): The dryer is of innovative technology since it allows the use of up to 50% of recycled material. Its interior is shaped in such a way as not to risk the recycled materials to come into contact with the flame while maintaining the microstructure of the asphalt. The six feeders channel aggregates to the new dryer, which because of its design achieves smooth heat increase with the least possible loss of energy.

Burner: The burner is suitable for use for gas operation. It has a temperature control system and fuel pump. The filler resulting from the treatment of aggregates is stored and removed from filters.

Sieves and mixer: Mixer has a weighing capacity of 4,300 kg and includes weighing system for hot aggregates and asphalt as well as bitumen's weighing feeding system with heated ramp. All materials entering the blender are weighed, while at the same time measurement of aggregates', sand's, asphalt, filler's and mixing temperature takes place.

Figure 7. Drying oven and installation of sieves and mixer

Storage silos: At the lower level of the tower there are warehouses for the final bituminous mixtures. There are three (3) silos, while each one is divided into two (2) apartments. There are two heated output exits of the material, while exiting the warehouses, the material is weighed by the use of load cells.

Bitumen tanks: Asphalt plant has three (3) storage tanks for common asphalt and one (1) tank for modified bitumen with a special stirring system of modern technology and maximum capacity of $70m^3$ each (total of $280m^3$).

Figure 8. Silos and bitumen tank

Recording system: All mentioned before, are recoded, while relevant data are available during production in an on-line system. The asphalt plant allows an innovative and pioneering for Greece recycling process, since the maximum energy saving has been achieved due to the design of the unit.

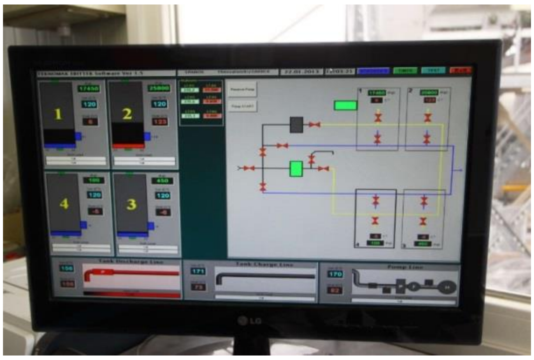

Figure 9. Recording system

3. Results- discussion

All mixtures have been examined as far as physical and mechanical characteristics are concerned. In particular, the following tests took place: gradation of the mixtures, Marshall test, calculation of stiffness @20^{O}C and rutting resistance.

- Gradation curves of all 4 compositions were inside limits set by ΕΛΟΤ ΤΠ 1501-05-03-11-04:2009. The main difference has been noticed in composition No4 which includes the use of RAP and asphaltite, since it comes over the critical zone.

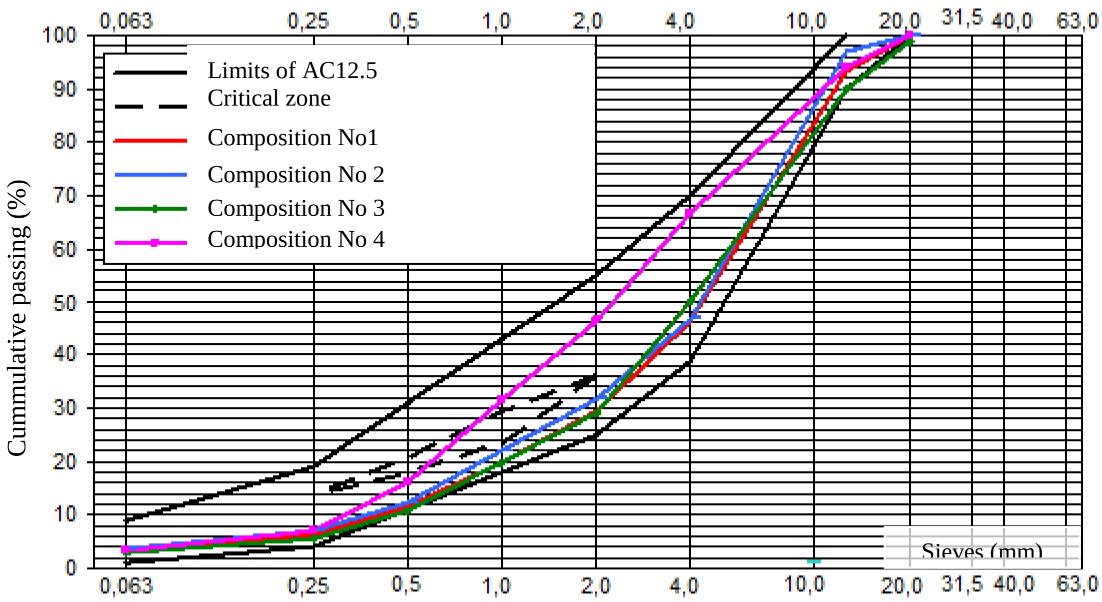

Figure 10. Gradation of final mixtures

- Addition of asphaltite as well as of RAP increased *stability* of the produced mixtures, while addition of both of them (composition 4) performed even better.
  Deformation was found to be inside limits set by ΕΛΟΤ ΤΠ 1501-05-03-11-04:2009 (2,0mm έως 3,5mm). Addition of RAP or asphaltite did not seem to change deformation despite the increase in stability.
  Detailed laboratory experimental results on Marshall Characteristics, which have been performed according to EN12697-6/-8/-34 are showed in Table 6, while photos of the tests can be found on Figure 11.

Table 6. Test results on Marshall characteristics

	Voids (%)	*VMA (%)*	*VFA (%)*	*Stability (kN)*	*Deformation (mm)*
1	4,10	14,10	70,70	8,5	2,8
2	3,80	14,5	73,80	9,49	2,9
3	4	14,40	72,10	12,81	2,7
4	3,70	13,70	73,40	13,08	2,5

Figure 11. Marshall test (stability and deformation of bituminous mixture)

- Addition of asphaltite in conventional mixture did not change significantly stiffness of the produced mixtures. On the contrary, addition of RAP as well as combined use of RAP and asphaltite was found to increase stiffness a lot. Detailed laboratory experimental results on stiffness of bituminous mixtures as performed according to EN12697-26 are showed in Table 7, while photos of the tests can be found on Figure12.

Table 7. Test results on stiffness @ 20^{o}C

	Mean height (mm)	*Stiffness MPa*
1	63.1	4133
2	62.9	5205
3	63.6	8981
4	63.6	10249

Figure 12. Testing stiffness of bituminous mixtures (according to EN12697-26)

- Addition of asphaltite was found to be beneficial as far as rutting depth is concerned, however composition with RAP showed even smaller rutting depth. Addition of both RAP and asphaltite increased rutting depth. Detailed laboratory experimental results on rutting depth of bituminous mixtures as performed according to EN12697-22 are showed in Table 8, while photos of the tests can be found on Figure 13.

Table 8 Test results on rutting resistance

	Rate of rutting (μm/ loading cycle)	*Rutting depth (mm)*
1	1.35	3.76
2	1.26	3.45
3	1.38	3.23
4	1.13	3.97

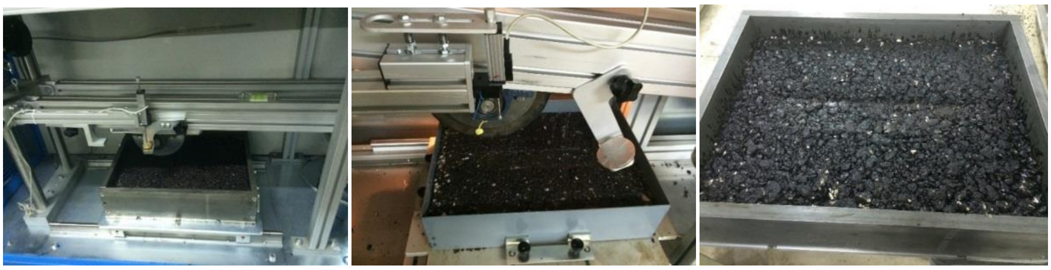

Figure 13 Rutting test

All test results as well as differences in percentage are showed on Table 9.

Table 9. Differences between properties of 4 compositions showed at percentage form

Composition	*Stability (percentage of difference %)*	*Deformation (percentage of difference %)*	*Stiffness (percentage of difference %)*	*Rate of rutting (percentage of difference %)*	*Rutting depth (percentage of difference %)*
Bitumen 50/70	*8,5 kN*	*2,8 mm*	*4133 MPa*	*1.35 (μm/ loading cycle)*	*3.76mm*
Bitumen 50/70 + Asphaltite	+12%	+3%	+25,9%	-7%	-8%
Bitumen 50/70 + RAP	+51%	-11%	+117%	+2,5%	-14%
Bitumen 50/70 + Asphaltite+ RAP	+54%	-10%	+148%	-16%	+5,5%

4. Conclusions

Given experimental results, basic conclusions of present research are the ones listed below:

- Conventional bituminous mixture with bitumen 50/70 satisfies the demands for bituminous layers in places of heavy circulation as set by Greek Specifications ΕΛΟΤ ΤΠ 501-05-03-11-04:2009.
- Addition of asphaltite at percentage of 12%w/t of bitumen improves, as expected, mechanical properties of the mixtures, however this improvement was not very significant. Rate of rutting and depth of rutting slightly decreased.
- Addition of RAP at percentage of 30% w/t of the aggregates leads to a significant improvement of the whole list of properties examined compared to the ones of the conventional mixtures.
- Combined use of RAP and asphaltite seems to improve further mixtures' properties apart from depth of rut, even though rate of rutting is improved.

Concluding the use of asphaltite does not change mixtures properties, while it increase the cost of them since its value comes up to 750€/tn (operational costs increase further since bituminous mixture's production with it is more time consuming). On the contrary, addition of RAP has many advantages. First of all properties of the mixtures are improved, cost is decreased since less bitumen and quantity of natural resources are used for the production of the final mixture and of course protection of the environment by saving natural resources is achieved while at the same time waste is exploited and raw materials are saved for next generations.
Unfortunately, Greek legislation allows at the moment the use of RAP at percentage up to only 10%w/t of the aggregates for surface bituminous layers and 20% for lower layers. Main result of present study is the

certification of excellent performance of mixtures with 30% of RAP. Moreover, addition of more than 30% can be studied and if performance is good and acceptable, wastes of category 17 03 02 won't be landfilled but utilized for the production of new mixtures, entering this way at a new life cycle of road pavements. Even a slight increase of percentage of RAP used in bituminous mixtures is beneficial and can lead to the achievement of goals as are set by the Greek legislation (KYA36259/1757/E103/24-08-2010) which demands the reuse and recycling of 70% of C&D Wastes by 2020.
However, it is still necessary to conduct more studies in order to improve the bituminous mixtures performance and contributing to an even more desired sustainable solution. However, this article certifies that the WMA with RAP is an innovative technology and it can be used in new pavements.

Acknowledgments

Authors would like to thank Anakyklosis Adranon Voreiou Ellados S.A and NIK. KAISIDIS SA for the support on the conduction of present research.

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