Pilot application of modified asphalt mixture with End of Life Tires (ELTs) and Reclaimed Asphalt Pavement (RAP)

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Abstract

The accumulation of huge quantities of waste tires is an environmental concern worldwide. There have been several studies on recycling of end-of-life tires, since these cannot be reused and are no longer accepted in landfills (Directive EU 31/99). Used tires are usually recycled for material recovery or used as tire-derived fuel (TDF) for energy recovery due to their high calorific value. Nevertheless, there is one application of End of Life Tires (ELTs) that is less common in Greece and this is the modification of asphalt mixture by crumb rubber from mechanical granulation of ELTs, which improves road properties.

This study, aims to investigate the properties of a pilot's demonstration road pavement such as skid resistance, rutting (wheel bolts) and noising. During the pilot implementation, pavements with modified asphalt and crumb tires and asphalt mixtures with participation of Reclaimed Asphalt Pavement (at a percentage of 30% and 50 %) and of ELTs crumb were applied, to substitute the coarse asphalt mixture. The pilot application of road pavement was conducted in Aspropyrgos, Greece. The results were compared to the conventional asphalt mixture, the modified rubber mixture and the modified rubber with different RAP percentages.

The assessment of the environmental impact was investigated under the following scenarios: a) conventional asphalt, b) modified asphalt and crumb tires mixture, c) modified asphalt, crumb tires and 30% RAP mixture and d) modified asphalt, crumb tires and 50% RAP mixture. The environmental impact of considered applications was analysed by means of the life cycle simulation software SimaPro.

Introduction

The population growth and the social-economic increase, create a continuous increase on the demand of vehicles and, thus to high discards of vehicles. The discard of the vehicles leads to high amounts of waste tires. However, vehicles require safe roads to move around.

The roads are the dominant part of the passenger transport and the transportation chain of goods. In the European Union (EU), in 2020, 87,2 % (% based on passengers-km) represents the transport by passenger cars and 77,4 % represents the freight transport, respectively by roads (EUROSTAT, 2022) [1]. Similarly, in Greece in 2020 the transport by passenger cars represents a percentage higher than 85 % and the freight transports higher than 90 %. According to Poulikakos et al [2], the road network needs significant amount of materials, such as aggregates, bituminous and cementitious binders and other additives to improve the properties of the new produced roads to face today's challenges. In the frame of sustainable growth and circular economy, the maximisation of the re-use of reclaimed asphalt pavement (RAP) as a component for new asphalt production [3] which is well established and commonly applied in Europe. Due to its aging, RAP is a hardened binder for new pavement mixture production. It is required to use a softer binder/agent, to restore the mechanical properties of RAP [4]. Piao et al [5], try to summarize the waste materials that could be used in asphalt surface course as binders, such as End-of-Life tires (ELTs), waste ceramics, waste plastics, polypropylene, polyethylene, polyvinyl chloride etc. The using of binders in asphalt mixture should not degrade the technical performance of the new bitumen. The agents derived from waste, should meet requirements as the respect of public health and environment [4]. Crumb rubber derived from ELTs is considered as alternative polymer that could improve performance of asphalt mixture.

According to Formela et al [6] 1000 million of End of Life Tires (ELTs) are released to the environment every year and the predictions show an increase to 1200 million in year 2030. Despite the fact that landfill of tires is forbidden in the EU from 2003 (2006 for shredded tires), it is still a practiced ELTs option in many countries. Other ELTs practices are the recycling for new raw material, the reuse as construction material and for energy recovery. The disposal of ELTs has considerable environmental importance, since huge space is required for landfilling, whilst ELTs have poor biodegradability and are easily combustible [7].

Data given from the European Tire and Rubber Manufacturers Association (ETRMA) shows that the vast majority of ELTs are recycled for the production of crumb rubber. In 2019, 95% of ELTs was treated for material recycling and energy recovery. The recycled material is an important resource for industries such as construction, automotive and cement [8].

Asphalt pavement is a complex combination of aggregates, binders and air voids [2]. Polymers could be used as modifiers to enhance asphalt pavement properties. However, there are two pilars for the re-using of the road pavement: a) save resources and b) improve new product properties. The first one concerns the re-use of old road pavements and waste for new pavements production with direct economic benefits and materials saving. As regards the improvement of their properties, Poulikakos et al [2], suggests to replace traditional materials with new, such as polymers. According to European Asphalt Pavement Association (EAPA) [3] in 2021, the road construction industry re-uses 72 % of RAP for new asphalt production in various applications (hot mixture asphalt, warm mixture asphalt etc), 25 % is recycled in unbound road layers and only 4 % is used in unknown applications or deposited to landfill.

The ELTs additives, prior to their mixing with the other materials, are chopped into crumb rubber particles according to the production process. Li et al [9] reports three mixing methods of ELTs crumb rubbers with asphalt binder, a) the wet method, b) the dry method and c) terminal blend process. Literature [10] refers that the additions of ELTs crumb can improve the properties of the asphalt pavement and could also improve the sustainability of waste disposal. According to Mohajerani et al [11], the addition of ELTs improve the performance of asphalt pavement, either by the dry or wet method of modified asphalt mixture production. Another study [2] claims to replace conventional material with ELTs crumb rubber in constructing roads and their use could reduce the density, improve drainage properties, provide good thermal insulation and reduce the noise. Moreover, refers that the use of ELTs in road construction could reduce the vibration between vehicle tire and road interface.

Although, a several LCA studies have been conducted in relation to road pavement with RAP usage or recycled waste streams [12,13], few studies have examined the environmental impact of a pilot pavement demonstration, combined with the participation of RAP and ELT.

This study aims foster the combined usage of ELTs and RAP in the road construction industry. For this reason, the physical and mechanical properties of modified asphalt mixture with RAP and ELTs usage in a pilot road application were investigated. On the demonstration road pavement skid resistance, rutting (wheel bolts) and noising were monitored. In addition, a LCA study was carried out on the carbon emissions of using ELTs and RAP during the construction of new roads.

Material and Methods

In our study, various tests were performed to determine the suitable mixture of materials for the new asphalt pavement through the wet or dry production process. After the completion of laboratory scale tests regarding the acceptable material rates of asphalt mixtures using the wet process method, the industrial scale mixtures production began. The latter were produced in a bitumen unit in Greece. For the pilot demonstration, an asphalt paving of a total length of 500 m was carried out in Aspropyrgos, Greece. Figure 1 illustrates the four types of road pavements, which were investigated.

Blending, Samples production and Road Pavement

Chopping ELTs

For the application in asphalt mixtures, the ELTs were chopped to fine crumb rubber granules with a size of 0-0,4mm. According to literature [9] the used types of tires in asphalt modification are treated rubber, heavy truck, small truck and agriculture truck tires. These types of tires perform different properties. Tires originated from heavy trucks and treat rubbers exhibit better results in asphalt modification. In this study, the tires sourced were passenger and heavy truck tires. Textile fibers and steel were removed before the use of ELTs in road pavement.

Asphalt modification

As already referred, the modification of asphalt was based on the wet method process. According to this method, the addition of ELTs crumb rubber was made gradually, to a total percentage of 5 % w/w in the final product. The homogenized temperature of asphalt mixtures was 180 °C for 3hrs.

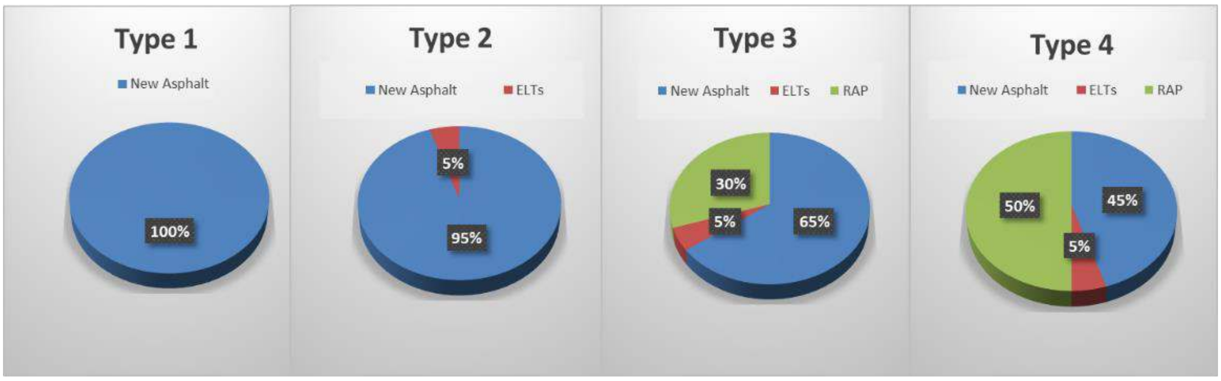

Figure 1. Trials for new asphalt production with various percentages of materials.

Road paving

As presented in figure 2, four different types of asphalt mixture were paved. In particular, 100 m was laid out with conventional asphalt, 150 m with asphalt and ELTs mixture, 100 m with a mixture of asphalt, ELTs and RAP at a 30 % rate and finally 150 m with a mixture of asphalt, ELTs and 50 % of RAP. The road pavement took place at the industrial area of Aspropyrgos, Greece, on a local road that connects the bitumen production plant to the NATO avenue. Prior to the new pavement, milling was carried out to a depth of 50 mm to remove the old pavement. Milling is a widely used technique for pavement recycling, where the pavement/surface layer is removed and ground up to be used as the aggregate in a new pavement. The new asphalt pavements were placed to a depth of 50 mm and surface area of 2,000 m^2, respectively.

Two measurement tests were performed at intervals of 4 and 8 months, after the paving of the new pavement sections were completed. This was done in order to examine the effect of pavement aging while studying specific pavement properties.

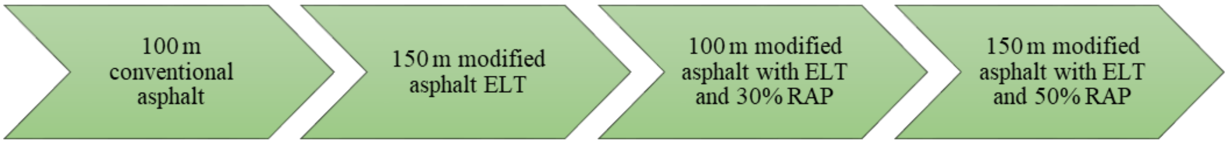

Figure 2. The road sections of total 500 m new asphalt pavement.

Acoustic Absorption (Noising)

Traffic noise originates from three sources: a) the noise from the engine and the exhaust of the vehicles, b) the aerodynamic of the bodywork and c) the interaction between tires and the road surface. The latter is considered as the most important source of noise. To minimise the noise, car manufacturers have developed quieter exhaust and engine systems, more aerodynamically efficient vehicle designs and tires with treads, designed to reduce the generated noise by tire-road contact [14]. The noise of the tire moving on the road surface is caused by the movement of particles in the tread voids and the vibration of the tire [15]. There is a space between the tire tread and the road surface that forms an acoustic horn, which increases the backward and forward transmission of sound radiation. There are many factors, that influence the noise associated with tire-pavement contact. These are the size and type of aggregate, vehicle speed, temperature, type of asphalt mixture, aging, thickness and texture of the pavement surface. However, the most important factor, is the porosity of the pavement. The porous material plays a part in creating and reinforcing of the noise, as absorption reduces the compression of trapped air between the tire and the road surface. The addition of the crumb rubber in the pavement increases the porosity of the asphalt resulting in increased noise absorption. According to literature [16], the usage of crumb rubber in mixtures could lead to a reduction of noise by 2,5 to 4 dB.

The noising measurements were carried out according to the standard ISO 11819:1 2001. Acoustics Measurement of the influence of road surfaces on traffic Noise Part 1: Statistical Pass by Method, with sound meters NTi XL2 and Bruel & Kjaer 2250.

Figure 3. Equipment station for noise/sound measurement of passenger car and truck.

The equipment was placed at 1,2 m height above the ground and about 4 m distance from the test lane, on which the vehicle is moving. The speed of the vehicles was kept constant at 40 km/h. To verify the results, sound measurements were taken on both moving directions. Initially, the background noise (blank) of the area without vehicles crossing was measured.

Table 1. Positions of the noise level measurement tests.

Position	Description
0	Old Pavement
1	100 m conventional asphalt
2	150 m modified asphalt with ELTs and 50% RAP
3	100 m modified asphalt with ELTs and 30% RAP
4	150 m modified asphalt with ELTs

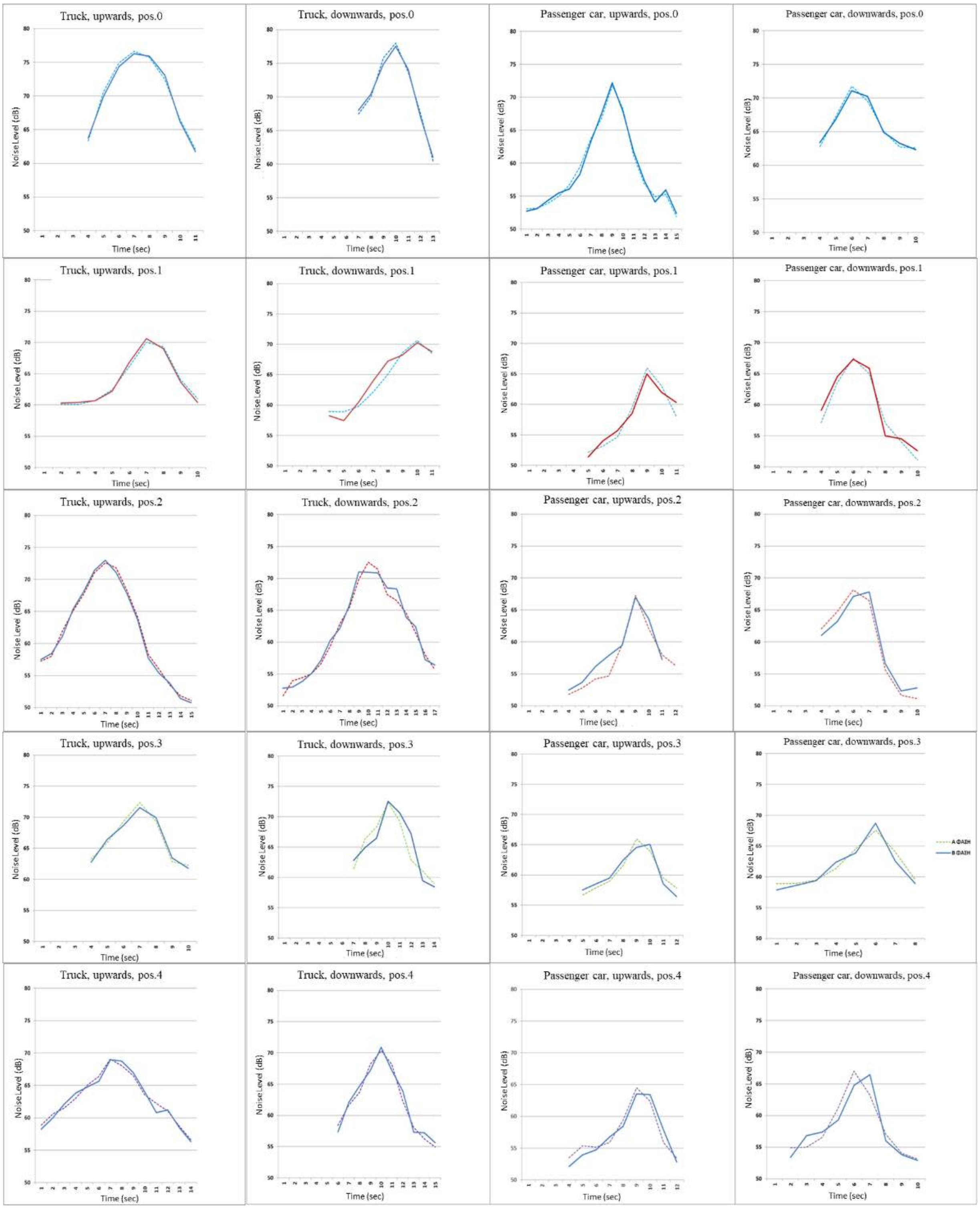

Figure 4. Acoustic Absorption, of trucks and passenger cars. The dashed line corresponds to the first stage of measurements whilst the continuous line to the second stage.

Skid Resistance

The result of skid resistance is a friction between the road surface and the vehicle tires, which prevents the vehicle from sliding on the road surface. Skid resistance relates to the need for an asphalt mixture to exhibit sufficient resistance to skidding, mainly under wet weather conditions. Skid resistance of vehicles depends on several factors, including vehicle speed, tire characteristics, weather conditions, road geometry and condition, microtexture and macrotexture of the road surface. Furthermore, the aggregate properties (texture, shape and size) are factors related to skid resistance [17]. The crumb rubber originating from passenger car ELTs improve skid resistance, due to the composition of passenger car tires, which includes higher content of synthetic rubber and black carbon in comparison to heavy vehicle tires [6].

The determination of skid resistance was carried out according to standard BS 7941-2:2000 with a Grip Tester (Findlay Irvine) equipment. Grip Tester is the most common used device for measuring the skid resistance in highways and airport runways. Measurements were accomplished in both directions (upwards and downwards) of the same road. The skid resistance was recorded at 5 m intervals. The higher the Grip Number is the better the skid resistance is. Figure 5 presents the skid resistance results of the four new pavement mixtures and the old one. The test was performed in two stages. The first stage took place on 22/05/2021 while the second one on 03/09/2021.

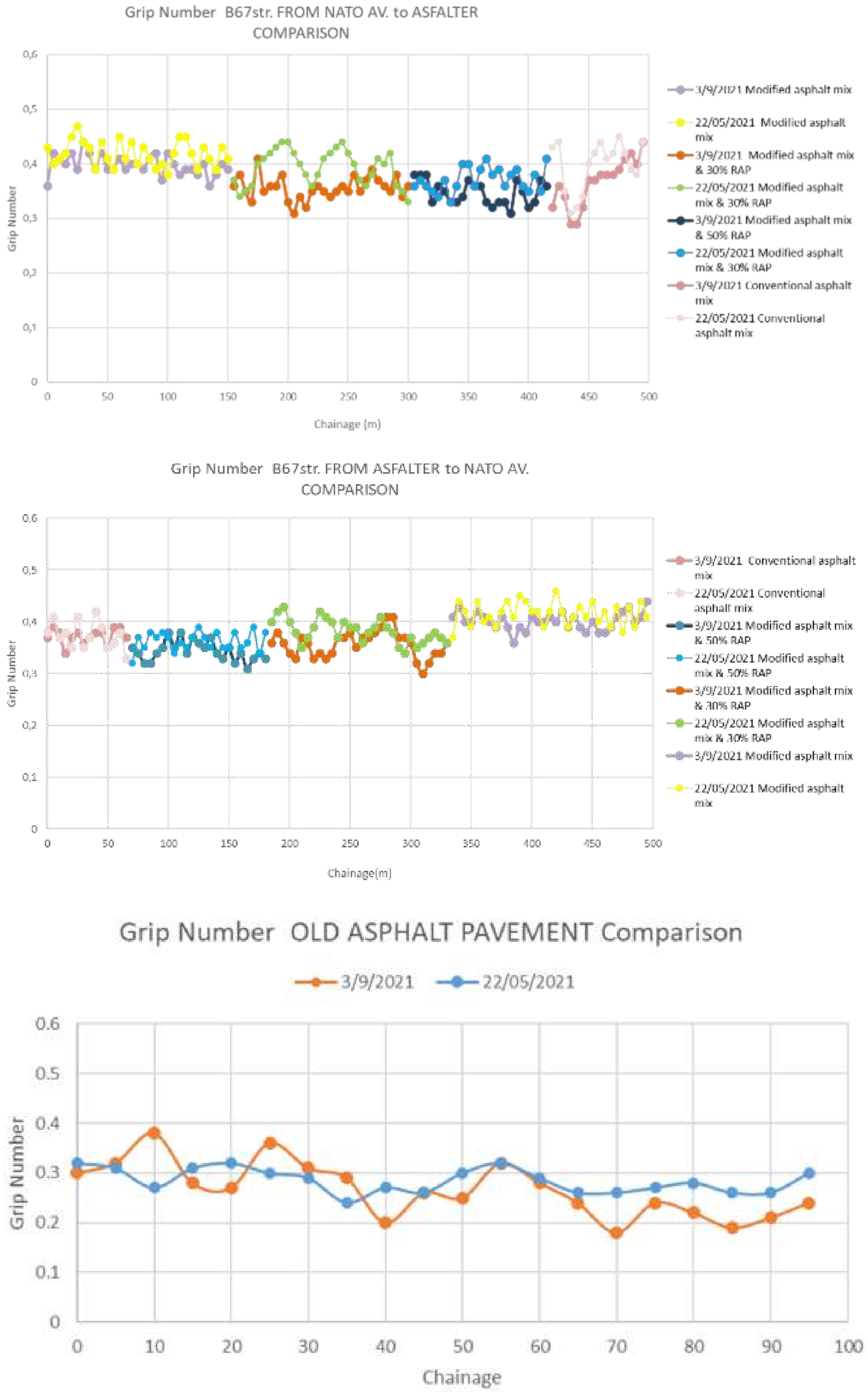

Figure 5. Skid Resistance Results of the new road pavements vs the old pavement.

Rutting (Wheels bolt)

The rutting phenomenon is the result of permanent deformation of the road surface. It can occur longitudinal to the road surface and usually it is a trace of the vehicles wheels. The result is a depth in the road surface, which causes driving difficulties and handling of the vehicle. Rutting is responsible for water retention on the road surface. The most common cause is high traffic and heavy loads on roads.

Bala et al [18], contends that the additions of crumb tires in asphalt pavement mixtures could provide better performance in terms of reducing the rutting phenomenon. The rutting tests were carried out according to the standard ASTM E2133-03, with a Walking Profiler equipment. The speed of the walking profiler was at 5 km/h. Twelve points on the road surface were measured, three on each type of road surface. The most representative points are presented in figure 5. The orange curve corresponds to the measurements on 22/05/2021 while the blue curve to the measurements on 03/09/2021, respectively.

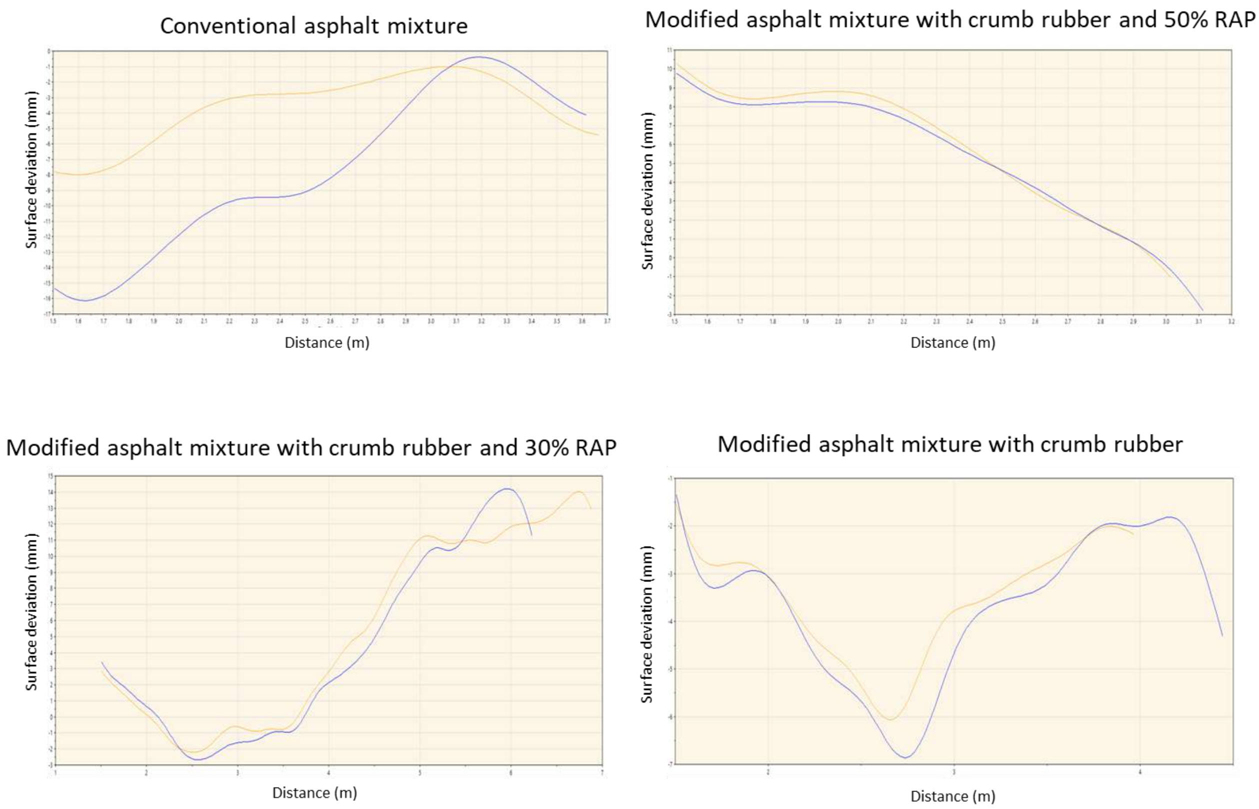

Figure 6. Rutting Test. A) Conventional asphalt mixture, B) Modified asphalt mixture with ELTs and 50% RAP, C) Modified asphalt mixture with ELTs crumb and 30% RAP, and D) Modified asphalt mixture with ELTs crumb

Splash and spray

The wet road surfaces affect the road safety. Apart from the pavement slipping, they could also create a splash mist and spray effect. Usually, this is attributed to the heavy trucks and leads to poor visibility for passenger car drivers. This condition increases the possibility of vehicles' accidents. The determination of splash and spraying tests was carried out from visual observation of photo frames, only for the conventional asphalt and the mixture of asphalt, ELTs and RAP in 30 % percentage. Due to the geometry of the site, it was not possible to take photo frames for the two other types of road pavements. The distance between the camera and the passing vehicle was insufficient. Prior to the measurements, a tanker passed and an equal amount of water was emptied on the surface of both tested pavements. To observe the splash and spray phenomenon a truck and a passenger car were used. The speed of the vehicles was constant at 40 km/h. In figure 7, are shown the splash and spray comparison of the two tested pavements.

Figure 7. Comparison of heavy truck and passenger car splash and spray photo frames. A) new conventional pavement and B) asphalt mixture with ELTs and 30 % RAP, C) new conventional pavement and D) asphalt mixture with ELTs and 30 % RAP.

Life cycle impact assessment

The environmental impact of greenhouse gas emissions for the modified asphalt mixture pavements comparatively to conventional asphalt was determined by means of the life cycle simulation software SimaPro PhD 8.2.3 version, according to Impact 2002+ methodology. The reduced CO_2 emissions were calculated on the existing production processes of bitumen.

Life cycle inventory (LCI)

The life cycle inventory analysis took into account all the environmental inputs and outputs associated with a particular product. The inputs and outputs, such as raw material, energy consumption, carbon emissions and waste streams, are collected and quantified throughout the life cycle assessment. The inventory for the conventional asphalt and the modified mixtures were provided by an asphalt mixture production plant. Table 2, shows the environmental assessment of the four exanimated scenarios based on fossil fuel energy sources.

Table 2. Overview of the environmental assessment of ELTs and RAP uses on asphalt modified mixtures.

	Conventional Asphalt	Modified asphalt mixture with ELTs	Modified asphalt mixture with ELTs and 30% RAP	Modified asphalt mixture with ELTs and 50% RAP
Asphalt mixture (tn CO_{2eq})	5,42	6,21	5,35	4,68
Emulsion (tn CO_{2eq})			0,36	
Pilot demonstration (tn CO_{2eq})			0,25	
Total emissions (tn CO_{2eq})	6,03	6,82	5,96	5,29
Emission CO_{2eq} per tn asphalt mixture (kg $CO_{2eq/tn}$)	26,26	29,37	25,48	22,46
CO_2 (%) emissions	-	11,84(▲)	-2,97(↘)	-14,47(↘)

Additionally, the required energy for the asphalt mixtures based on alternative fuels (renewables and fossil fuels) was defined. In this case, the use of renewable energy sources at a percentage of 50 % or 90 %, could reduce the CO_2 emissions from 7 % to 23 % for the modified asphalt. The reduction of CO_2 emissions in modified asphalt with crumb rubber and RAP could reach 22 % to 48 %, respectively. Table 3 shows the CO_2 emissions of the modified asphalt production process using alternative fuels. The carbon emissions were calculated on the combination of Impact 2002+ and Greenhouse Gas Protocol methodologies.

Table 3.CO_2 % reduction using alternative fuels in asphalt mixture production process.

	Modified asphalt mixture with ELTs	Modified asphalt mixture with ELTs and 30% RAP	Modified asphalt mixture with ELTs and 50% RAP
50 % RES and 50 % Fossil Fuel/Biodiesel			
Total emissions (tn CO_{2eq})	5,66	4,79	4,12
Emission CO_{2eq} per tn asphalt mixture (kg $CO_{2eq/tn}$)	24,38	20,48	17,50
CO_2 (%) emissions	-7,19(↘)	-22,02(↘)	-33,39(↘)
90 % RES and 10 % Fossil Fuel/Biodiesel			
Total emissions (tn CO_{2eq})	4,73	3,87	3,23
Emission CO2eq per tn asphalt mixture (kg CO_{2eq}/tn)	20,37	16,54	13,72
CO_2 (%) emissions	-22,44(↘)	-37,00(↘)	--47,78(↘)

Results and Discussion

The modified asphalt with ELTs participation performed the lowest results in the noising test for all the vehicle types, whilst the modified mixtures with RAP at 30 % and 50 % percentage addition performed similar noise results as the conventional asphalt. The highest noise level values were observed on the old asphalt pavement. Especially, the participation of ELTs in asphalt mixtures reduced the noise level in both measurement periods. The highest level noise of a passenger vehicle (moving at upward direction) in modified asphalt with ELTs addition reached 64 dB, whilst passenger vehicles' level noise reached 72 dB compared to the other asphalt mixtures. There was a difference of 8 dB between these measurements. The same difference of 8 dB between the asphalt mixture measurements were also presented at downward direction moving, for both passenger and truck vehicles.

According to the above, the modified asphalt with ELTs performs the best in terms of noise level. The four types of asphalt pavements exhibit similar values of noise level. This facilitate the use of ELTs and RAP up to 50 % for new pavement production. Bueno et al [19], claims that the use of crumb rubber reduces the vibrations from tire to pavement interaction, which are the cause of the produced noise. However, he reports that the process production and compacting of the asphalt mixture are critical points for the acoustic behaviour and the final effects on the surface properties.

In skid resistance tests, in both road directions, a small decrease of the grip number is observed, due to the higher traffic load of the pavement between the two stages of the measurements. The modified asphalt with ELTs crumb had the best performance. Especially, at the first stage of skid resistance tests, the modified asphalt had average grid number values around 0,42 for both movement directions. The modified asphalt with ELTs and 30 % RAP had average grid number values in between 0,38 and 0,39, movement upwards and downwards, respectively. The average grip number for the mixture with ELTs and 50 % RAP showed values of 0,37 (upward movement) and 0,36 (downward movement). The new conventional asphalt presented average grip number values ranging in between 0,40 and 0,38 in both moving directions. At the second stage, the modified asphalt presented average grip number values of 0,40 and 0,31, in both movement directions. The average grip number of the other mixtures with RAP and conventional asphalt, remained almost constant for either upward or downward movement, as illustrated in figure 5.

As shown in figure 6, the rutting was not significantly affected between the two measurement stages for all types of pavements. There was no difference in modified asphalt pavements in rutting at the two periods of measurements. Deterioration is observed of rutting in the second period measurement for the conventional asphalt, whilst on the pavement with ELTs and 50 % RAP it remained almost unchanged.

Several studies [20, 21, 22], referred that the addition of crumb rubber improves the skid resistance, reduces fatigue cracking and exhibits longer pavement life than conventional bituminous mixtures. Furthermore, the participation of ELTs provides more comfortable driving [23]. Regarding the use of RAP, there are limited studies for the pavement performance and further research is needed. The use of RAP seems to be beneficial to the pavement properties, but it is considered a potential factor for thermal cracking [24].

Studies based on the effect of RAP and crumb rubber on hot asphalt mixtures concluded that the use of crumb rubber is beneficial in increasing fatigue resistance, but the increase of RAP content results in a decrease of fatigue resistance. At the same time, RAP could increase resistance against wheel rutting, but has an impact on resistance against low temperature induced cracking. However, the use of both materials in amounts of 10 % crumb rubber and 25% RAP could provide the desired results towards improving resistance to wheel rutting and pavement fatigue. Finally, both RAP and crumb rubber were found to perform better at high temperatures, making them suitable for use in hot climates [25, 26, 27]. The pavement is affected by the adhesive properties of the asphalt mixture. Conventional asphalt consists of poor range of rheological and durability properties, which are not enough to keep the pavement from getting worse with more traffic and weathering [13].

Based on the visual observation, it is obvious that the better splash and spray state is in modified asphalt with crumb rubber and 30% RAP than in the conventional asphalt. Shirini and Imaninasab [28] showed that the addition up to 15% of crumb rubber in porous asphalt increases the drainage. Even, Sangiorgi et al [29], claimed the positive influence in draindown tests of crumb rubber addition in comparison to porous asphalt without additives.

The LCA impact was calculated by using life cycle inventory data. The LCA results demonstrated that the addition of crumb rubber in asphalt mixture increases the CO_2 emissions by 11,84 % compared to the conventional asphalt mixture production. Nevertheless, the mixtures with ELTs crumb and RAP in 30% and 50% are eco-friendly, with CO_2 reduction in 2,97 % and 14,47 %, respectively. Furthermore, if the energy demand for the production of asphalt mixtures is covered by alternative fuels, as illustrated in table 3, the recycled materials are more efficient. In particular, the modified asphalt mixture with crumb rubber could reduce the CO_2 emissions from 7,19 % to 22,44 %. The mixtures with ELTs and RAP could reduce the CO_2 emission from 22,02 % to 47,74 %.

As is it noticed, the modified asphalt combined with ELTs and RAP, produced by wet technology, leads to promising results as regards the energy savings, carbon emissions reduction, resources depletion and sustainable ecosystem.

Conclusions

This study aims to investigate the mechanical properties of new mixtures for road pavement. The results in skid resistance, rutting, acoustic absorbance and visibility loss are promising for the usage of ELTs crumb and RAP in asphalt mixture. Moreover, two waste streams could be utilized. The first one is the ELTs stream, which could increase the recycling percentage of ELTs as raw material production with consequent environmental benefits. The other one is the RAP stream, which could also increase the percentage of RAP usage in asphalt at over 20 %. According to literature [2,20] the addition of crumb rubber improves fatigue and cracking, reduces noise, yields longer pavement life and leads to high savings in CO_2 emissions (during construction and maintenance of the pavement). On the other hand, the aged binder (RAP) leads to cracking and rutting results [30]. The combination of the ELTs crumb and RAP produce a durable asphalt mixture with constant properties.

In the comprehensive LCA study, the modified asphalt with crumb ELTs contributes to increase the CO_2 emissions rather than conventional asphalt mix. However, the applications of asphalt, crumb ELTs and RAP at a 30 % and 50 % percentage, were more efficient either using only fossil fuels or alternative fuels. The first could reduce greenhouse gas emissions from 7 % to 23 % and the second one up to 48 %.

Environmental benefits and the improved properties of asphalt mixture using recycled aggregates such as ELTs and RAP should be in line with appropriate legislation and standards, which should be reviewed in this context when referring to the use of waste for the construction of road pavement.

Finally, it would be interesting to investigate further the use of ELTs and RAP in a highway with heavy traffic load. Also, to investigate the performance of the mechanical properties of pavement in aging.

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