World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:4, No:6, 2010

Comparison of Conventional and “ECO” Transportation Pavements in Cyprus using Life Cycle Approach

Constantia Achilleos and Diofantos G. Hadjimitsis

Open Science Index, Civil and Environmental Engineering Vol:4, No:6, 2010 publications.waset.org/987.pdf

***Abstract*—**Road industry has challenged the prospect of eco-construction. Pavements may fit within the framework of sustainable development. Hence, research implements assessments of conventional pavements impacts on environment in use of life cycle approach. To meet global, and often national, targets on pollution control, newly introduced pavement designs are under study. This is the case of Cyprus demonstration, which occurred within EcoLanes project work. This alternative pavement differs on concrete layer reinforced with tire recycling product. Processing of post-consumer tires produces steel fibers improving strength capacity against cracking. Thus maintenance works are relevantly limited in comparison to flexible pavement. This enables to be more eco-friendly, referenced to current study outputs. More specific, proposed concrete pavement life cycle processes emits 15 % less air pollutants and consumes 28 % less embodied energy than those of the asphalt pavement. In addition there is also a reduction on costs by 0.06 %.

***Keywords*—**Environmental impact assessment, life cycle, tire recycling, transportation pavement.

I. INTRODUCTION

GREENHOUSE gas emissions are constantly increasing and causing climate change effects. Reference [1] reports the case of Cyprus in which emissions are raising from 6 Mt CO_2-eq in 1990 to 12.2 Mt CO_2-eq in 2010. These projections demonstrated great influence in emission increase of fuel consumption in energy industries, transport and process related emissions from mineral products. Targeting reduction in air emissions, the current study introduces a new technique in road construction to minimize emissions mainly in energy, transport and mineral industry. Moreover the proposed “eco” pavement may derive additional benefits, such as minimizing traffic during maintenance actions or use recycle aggregates in layer mix design.

Life cycle approach was used to estimate the environmental and economical picture of the proposed long lasting rigid road pavement (LLRP). Transportation studies often compare environmental impact and energy consumption of alternative pavements following life cycle assessment (LCA) methodology, as in [2]–[4]. On the other hand life cycle cost analysis (LCCA) is a very common in calculating pavement cost for the road constructor and mainly for the road user. The objective of the study is to present the environmental and economical evaluation of a rigid steel fiber reinforced roller-compacted concrete pavement (SFR-RCC) constructed in Cyprus as a demonstration project within the work framework of EcoLanes FP6 STREP project funded by EU, titled “economical and sustainable pavement infrastructure for surface transport” project. For comparison purpose, it includes also four alternative pavements: bituminous flexible and three wet, reinforced or not, concrete.

EcoLanes aimed the development of pavement infrastructure using roller compaction techniques, based on existing asphalt laying equipment, and dry concrete mixes reinforced with steel tire-cord fibers. This new construction concept was expected to reduce construction costs, construction time, energy consumption in road construction; to minimize maintenance; to use post-consumer materials in road construction; and to make tire recycling more economically attractive [5]. The results of the project were validated by constructing full-scale demonstration projects in four diverse European climates and economies: Cyprus, Romania, Turkey and United Kingdom [6].

II. LIFE CYCLE APPROACH IN PAVEMENT CONSTRUCTION

LCA studies the environmental aspects and potential impacts throughout pavement life cycle: acquisition and processing of raw materials; construction and maintenance activities; distribution of materials and equipment from and to the construction site; traffic congestion during construction and maintenance; usage; and end of life, accounting for road demolition [7].

This ‘holistic’ approach has been constantly used and gradually developed in road industry research. Generally the main objective was to produce new construction techniques to minimize any potential negative impacts and, not rarely, to evaluate the use of waste materials as a recycling alternative.

C. Achilleos is with the Department of Civil Engineering & Geomatics, Cyprus University of Technology, Archbishop Kyprianos 31, Limassol Savings Co-operative Bank Building, 3603 Lemesos, Cyprus (25-00-2352; 25-00-2769; constantia.achilleos@cut.ac.cy).

D. G. Hadjimitsis is with the Department of Civil Engineering & Geomatics, Cyprus University of Technology, Archbishop Kyprianos 31, Limassol Savings Co-operative Bank Building, 3603 Lemesos, Cyprus (d.hadjimitsis@cut.ac.cy).

This paper presents tasks implemented within the framework of EcoLanes project, funded under the priority thematic area of Sustainable Surface Transport of the 6th framework program of the European Community.

However there is an increase risk of toxic substances leaching behavior, leading to the restriction in the by-products' reuse, such as the authorities in Sweden [8]. Comparing disposal scenarios of bottom ash in Denmark, it was concluded that water eco-toxicity is less in the case of landfilling than utilization in road construction [9]. Though there are greater potential savings of natural gravel in road scenario. Blast furnace slag (BFS) produced in iron extraction, was also rejected in France as an alternative material for road construction, even though it contributes to BFS recycling [10]. Yet some of the by-product constructions, such as the BFS and crushed concrete, showed greater environmental benefits compared to conventional construction [2], [11]. This can, though, be reversed by modifying the transportation distance ratio of the by-product to natural aggregate [12].

On the other hand, LCCA evaluates the economic values of a product's life cycle processes and flows. Rather often LCCA is used as an investment decisions tool. The analysis can demonstrate cost advantage among pavement alternative designs prior the construction phase. University of Michigan concluded that concrete overlay costs less than hot mixed asphalt overlay. Yet user cost accounts for more than 80% of total life cycle cost since cost distribution is driven by traffic parameters [7]. However concrete pavement has extensive life cycle to 40 years, half of the asphalt pavement, therefore maintenance works cost dominates on asphalt pavement life cycle cost [6]. In addition SFR-RCC reinforcement used in Cyprus demonstration can replace the expensive purchase and installation cost of rebars. Tire recycling plants may also be a more desirable facility for deposit than landfilling, in which there is high taxation fee.

III. DEMONSTRATION SITE IN CYPRUS

The area under investigation is located in Paphos rural district and is situated between the villages Pentalia, Galataria and Koilinia. Fig. 1 shows the road location (in circle) as part of the two-lane Galataria-Koilinia rural road. The area is hilly to mountainous with altitude 740 m above sea level [13]. Demonstration pavement covers an area of 60 m^3, length 40 m and width 6 m.

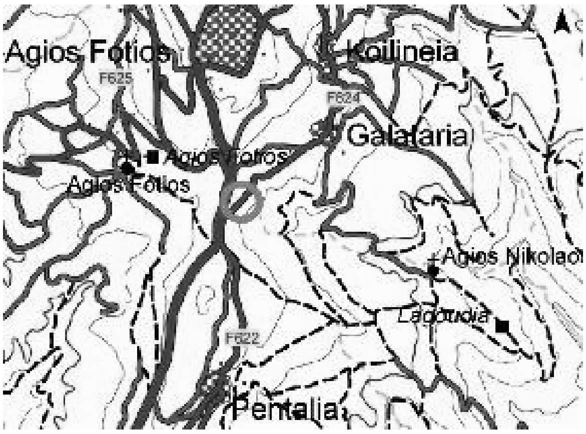

Fig. 1 Demonstration location near Galataria village

The demonstration pavement design is in accordance with the recommendations of the Romanian Standard NP 081-2002 which is mostly very near to the Cyprus "Public Work Department Design Pavement Manual". The pavement design is illustrated in Fig. 2. Due to the previous landslides, it was recommended by the Cyprus Geological Survey Department that the road should not be disturbed. Therefore prior pavement construction, the asphalt wearing course was only ground up using milling machine and the existing foundation (local stone) was maintained [13].

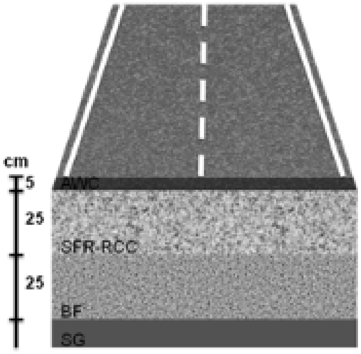

Fig. 2 Demonstration pavement design (AWC: asphalt wearing course, BF: ballast foundation, SG: sub-grade)

SFR-RCC laying included works implemented in asphalt placement. Firstly SFR-RCC mixture was fed into an asphalt paver, in which placed it in a single 30cm-layer thick. Compaction followed from the surface by using the tamping, vibrating, and pressing compacting systems of the paver and vibratory rollers. Fig. 3 shows compaction works by a roller. This resulted in working width, 25cm-paving depth, transverse road profile, surface accuracy, and surface texture of the highest possible quality achievable for roadway pavements. Finally an asphalt top layer was placed for better riding surface and noise reducing properties [14].

Fig. 3 Roller compacting SFR-RCC layer during demonstration day.

IV. OVERALL METHODOLOGY

LCA and LCCA were implemented for five alternative pavements, shown in Fig. 2 and 4. This included an Inventory Analysis to assemble input data from local and literature sources. Visits were organized to industries for data collection, such as, quarries, asphalt plant, concrete plant, cement plant, road constructors etc. In order to execute work, actions involved collection of data for energy consumption, air emissions and costs, and, in addition, relevant information, i.e. material quantities, mixing designs for asphalt and cement concrete, laying equipment time, purchase costs, labor costs, laying costs, transportation distances etc.

Finally the dataset was inputted in a LCA and LCCA software tools, named Gabi and CUT (developed by Cyprus University of Technology) respectively. The output parameters were used for an Impact Assessment in order to derive conclusions on the alternative pavements' results.

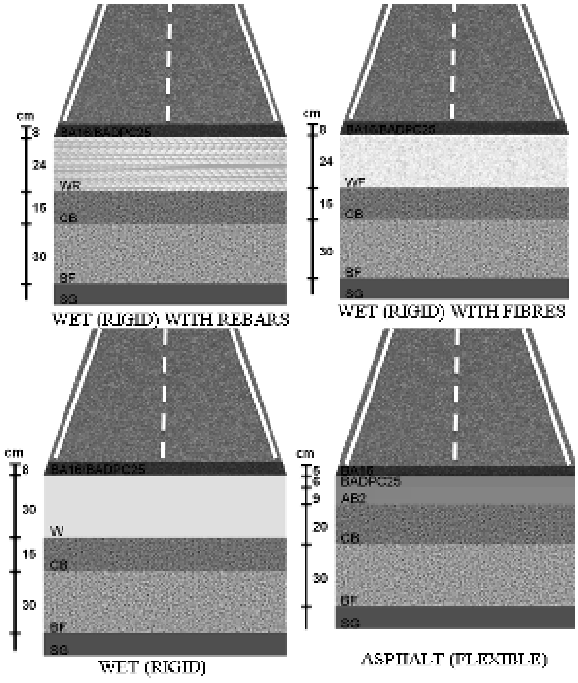

Fig. 4 Alternative pavement design structures under study.

V. RESULTS

Output parameters of the LCA and LCCA were used to assess of alternative pavements impacts on environment and market prices. Life cycle duration of every pavement was set equal to 40 years in order to have a common scale of comparison. The chosen impact indicators are: (i) primary energy consumption in MJ; (ii) embodied energy consumption in MJ; (iii) overall airborne emissions in kg; (v) construction and maintenance calculated (overall) costs in euro currency; (vi) agency costs in euro currency; (vii) and user costs in euro currency.

A. Energy resource consumption and environmental impact indicators

Energy consumption in system processes is defined as primary and produced in local plants. However, embodied energy is to find the sum of the energy necessary for a pavement life cycle. In more specific embodied energy is the sum of primary and feedstock energy, which was included in bitumen used for asphalt and prime/tack coat production. The reason is that crude oil is an energy source but in this case of bitumen production is not being used as an energy source [4].

In Table 1 shows energy consumption and air emissions results. Energy (primary or embodied) consumption is quite lower in the SFR-RCC pavement relevant to the other alternatives. More specific the SFR-RCC pavement consumes around 59 % less total energy (primary or embodied) than the asphalt pavement does. Wet concrete pavements' energy consumption is elevated in comparison to the proposed pavement. The reason of the insignificant difference on the energy consumption of the wet concrete pavements is the similarity in road design and mix design.

Total air emissions of the SFR-RCC pavement are the lowest values with almost 58 % less than the asphalt pavement. The reason is the rehabilitation activities of the asphalt pavement in 20 years, at the middle of the pavement life cycle. The wet concrete pavements have less environmental loadings than the asphalt pavement. Diversity on concrete layer depth and mix design causes the above variation on values. Wet (plain) concrete pavement holds greater values due to higher layer depth.

Based on LCA results the proposed SFR-RCC pavement is found as the most environmentally sustainable alternative in the road construction industry.

TABLE I
RESULTS OF ENERGY CONSUMPTION AND AIR EMISSIONS

Pavement type	Primary energy consumption (10^3 MJ)	Embodied energy consumption (10^3 MJ)	Overall airborne emission (10^3 kg)
SFR-RCC	218968.8	220730	218663
Wet reinforced with rebars	255964	262547	238786
Wet reinforced with fibers	255964	262547	238786
Wet (plain)	255964	262547	238786
Asphalt	294088	306616	259616

B. Cost analysis

Cost analysis results are summarized in Table 2. Regarding overall (construction and maintenance) cost, wet concrete reinforced with rebars pavement costs are the highest in relation to the other four alternative pavements. This occurs mainly due to the raw material purchase costs and mainly to the high purchase cost of rebars. The SFR-RCC pavement construction is the least expensive, approximately 15 % less than wet concrete reinforced with rebars pavement cost, due to the lower maintenance costs and raw material purchase costs. Similarly the alternative agency cost of the alternative pavements reveals higher values in the case of the wet concrete reinforced with rebars pavement. The SFR-RCC pavement agency cost is 16 % less than the wet concrete reinforced with rebars pavement agency cost. Asphalt pavement holds the lower agency cost because of the lower construction cost. User cost of the rigid pavements is 94 % less than asphalt pavement cost. Hence the asphalt pavement will cause the highest inconvenience to the road users. The reason of the higher user cost is the maintenance works, especially the necessary rehabilitation of the pavement in the middle of the pavement life-cycle.

TABLE II
RESULTS OF COST ANALYSIS

Pavement type	Overall cost (10^3 €)	Agency cost (10^3 €)	User cost (10^3 €)
SFR-RCC	218164.85	370.11	311.85
Wet reinforced with rebars	218167.72	442.96	312.130
Wet reinforced with fibers	218167.72	413.6	312.130
Wet (plain)	218167.72	441.41	312.130
Asphalt	218294.874	331.54	5696.3

Based on LCCA output, user cost of asphalt pavement is much higher than the rigid pavements. This cost is more significant as minor inconvenience of road users is more desirable, even if the agency cost of the SFR-RCC pavement is higher than the asphalt pavement. This occurs because of the rehabilitation activities in the asphalt pavement every 20 years. In this process the asphalt layers are milled and re-layered.

VI. CONCLUSIONS

In conclusion the proposed SFR-RCC pavement represents an environmental sustainable design for road construction industry. Aiming to green technologies and methodologies for construction, it is an ideal alternative for every part of the globe. Plain design methodology, common laying and material production equipment and less environmentally loadings, SFR-RCC pavement may be the ideal new approach in road construction.

Moreover SFR-RCC pavement is a more economically preferable alternative than the traditional asphalt pavement and the wet-consistency concrete pavements. Finally the asphalt purchase and laying costs affect the asphalt pavement final cost.

At the end the LCA dataset should be revised and updated with in-situ monitoring of emissions. Although this is an extremely difficult to achieve task, data quality is significant to be obtain for more accurate conclusions. These data are unavailable in local level, and therefore authors were forced to use literature sources. However most of the cases emission factors published by international and European organization may not apply in a specific region.

REFERENCES

[1] European Environment Agency, "Greenhouse gas emission trends and projections in Europe 2007 - Cyprus profile," EEA Report No 5/2007, 2007 [Online]. Available: http://www.eea.europa.eu/publications/eea_report_2007_5/Cyprus.pdf.

[2] U.-M. Mroueh, *et al*, "Life cycle assessment of road construction," Finnish National Road Administration, Finland, Finnra Rep. 17/2000, 1999.

[3] H. Stripple, "Life cycle assessment of road – a pilot study for inventory analysis," IVL Swedish Environmental Research Institute, Sweden, 2001, (2nd ed.).

[4] Athena Institute, "A life cycle perspective on concrete and asphalt roadways: embodied primary energy and global warming potentials," Rep. A-1, Canada, 2006.

[5] D. G. Hadjimitsis, K. Themistocleous and C. Achilleos, "Life cycle costing of a new transportation pavement constructed in the Paphos district area in Cyprus as a pilot study of the EcoLanes project," presented at the CEMEPE & SECOTOX Con., Mykonos, GR, June 21-26, 2009.

[6] D. G. Hadjimitsis *et al*, "Life cycle costing and assessment for innovative transportation pavement in Cyprus," presented at the In. Con. MAIRE PAV 6, Torino, IT, July 8-10, 2009.

[7] H. Zhang, G. A. Keoleian and M. D. Lepech, "An integrated life cycle assessment and life cycle analysis model for pavement overlay systems," in *Proc. 1st International Symposium on Life-Cycle Civil Engineering*, Varenna, Italy, 2008, pp 907-912.

[8] L. Roth and M. Eklund, "Environmental evaluation of reuse of by-products as road construction materials in Sweden," *Waste Management*, vol. 23, pp. 107-116, 2003.

[9] H. Birgisdóttir, G. Bhander, M. Z. Hauschild and T. H. Christensen, "Life cycle assessment of disposal of residues from municipal solid waste incineration: recycling of bottom ash in road construction or landfilling in Denmark evaluated in the ROAD-RES model," *Waste Management*, vol. 27, pp. 75-84, 2007.

[10] S. Shahinaz, A. Ventura, T. Hoang, D. François and A. Jullien, "Sensitivity of the LCA allocation procedure for BFS recycled into pavement structures," *Recourses, Conservation and Recycling,* vol. 54, pp. 348-358, April 2010.

[11] U.-M. Mroueh, P. Eskola and J. Laine-Ylijoki, "Life-cycle impact of the use of industrial by-products in road and earth construction", *Waste Management*, vol. 21, pp. 271-277, June 2001.

[12] R. Chowdhury, D. Apul and T. Fry, "A life cycle based environmental impacts assessment of construction materials used in road construction," *Recourses, Conservation and Recycling,* vol. 54, pp. 250-255, February 2010.

[13] D. G. Hadjimitsis, *et al*, "Environmental impact and energy consumption of transport pavements in Cyprus," in *Proc. 11th Int. Con. on Environmental Science*, Crete, 2009, pp. A-419-425.

[14] K. Neocleous, *et al*, "Development of a new type of concrete pavements: demonstration road in Pafos," "Ανάπτυξη νέου τύπου οδοστρώματος σκυροδέματος: πιλοτικός δρόμος στη Πάφο (in Greek)," in *Proc. 16th Hellenic Concrete Con.*, Paphos, 2009, Vol. D, pp 489-500.

Constantia Achilleos hold a BSc degree in Geology from the University of Athens, Greece, from 2004. She has also MSc degree in Applied Environmental Geology from Cardiff University, UK, gained in 2005.

She has 4.5 years of research and consulting experience in environment. She was employed as Environmental Consultant at a Cypriot consulting enterprise. She has also worked in a NGO as Research Officer for almost 1 year. Currently and for the last year, she is working as a Research Fellow in Cyrus University of Technology, Limassol, Cyprus. Through her work experience, she was mainly interested in environmental pollution, in specific, pollution to water and air. She is planning to continue her research career as a PhD candidate in Medical Geology, in order to be train on "environment and public health" field.

Ms. Achilleos is a member in Scientific and Technical Institute of Cyprus, Cypriot Geologists and Mining Engineers Society, and International Medical Geology Association.

Diofantos G. Hadjimitsis is an Associate Professor at the Department of Civil Engineering & Geomatics of the Cyprus University of Technology (CUT). He obtained a Higher National Diploma in Civil Engineering from the Higher Technical Institute, Nicosia, Cyprus, in 1992. He obtained a BEng. degree in Civil Engineering from the University of Surrey, UK, in 1996. He also obtained a MSc award in Real Estate and Property Management, from the University of Salford, UK, in 2007. He holds a MPhil degree in Satellite Remote Sensing from the University of Surrey, UK, from 1997 and a PhD degree in Civil Engineering from the University of Surrey, UK, from 1999.

He worked as a Teaching Assistant at the University of Surrey, as a Post-Doctoral Research Fellow and Visiting Research Scientist at the University of Southampton. He worked at the FIT (Cyprus) from the posts of Lecturer and Assistant Professor. . He joined CUT at 2007 as an Assistant Professor. He was working in the construction industry on Managing and Supervising various town-planning projects in Cyprus. He worked also as a Managing Director of a consultancy company working in the fields of remote sensing and GIS. He has been appointed as a Consultant by governmental departments in the fields of remote sensing, GIS and construction of town-planning projects. Some of articles publish are:

D. G. Hadjimitsis *et al*, “Life cycle costing and assessment for innovative transportation pavement in Cyprus,” presented at the In. Con. MAIRE PAV 6, Torino, IT, July 8-10, 2009.

D. G. Hadjimitsis ,C.R.I. Clayton and A. Retalis, “The use of selected pseudo-invariant targets for the application of atmospheric correction in multi-temporal studies using satellite remotely sensed imagery,” *International Journal of Applied Earth Observation and Geoinformation*, vol. 11, June 2009, pp. 192-200.

D. G. Hadjimitsis, “Aerosol optical thickness retrieval over land using satellite image-based algorithm,” *Air Quality, Atmosphere & Health*, vol. 2, June 2009, pp. 89-97.

D. G. Hadjimitsis, “Description of a New Method for Retrieving the Aerosol Optical Thickness from Satellite Remotely Sensed Imagery Using the Maximum Contrast Value and Darkest Pixel Approach,” *Transactions in GIS Journal*, vol. 12, October 2008, pp. 633-644.

D. G. Hadjimitsis, *et al*, “Satellite remote sensing for water quality assessment and monitoring-an overview on current concepts, deficits and future tasks,” *WSEAS Journals Transactions on Signal Processing*, vol. 3, January 2007, pp.67-71

D. G. Hadjimitsis ,C.R.I. Clayton and V.S. Hope, “An assessment of the effectiveness of atmospheric correction algorithms through the remote sensing of some reservoirs,” *International Journal of Remote Sensing*, vol. 25, September 2004, pp. 3651-3674.

His main research interests are focused on satellite remote sensing and GIS for civil and environmental engineering applications, construction management, pavements and materials for highway construction, geodesy applications.

Open Science Index, Civil and Environmental Engineering Vol:4, No:6, 2010 publications.waset.org/987.pdf