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Sustainable Pavements and Road Materials

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Table of contents

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Sustainable Pavements and Road Materials

(F. Russo, S.A. Biancardo, R. Veropalumbo and F. Abbondati)

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Driving behaviour: the impact of the Advanced Driver Assistance Systems and the Smart Road on the road safety

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Abstract

The study of the gaze is an indirect measure of cognitive processes and allows the evaluation of visual behaviour. Using highly technological instruments of eye-tracking is possible to define parameters that analyse, including knowledge of the kinematic characteristics of the vehicle, and how road safety can change the human factor. This assessment can be applied in different areas, such as the evaluation of the effectiveness of new Advanced Driver Assistance Systems (ADAS) and infrastructure elements related to Smart Roads [1,2]. The study of one of the main ADAS, the Adaptive Cruise Control (ACC), should highlight how the 'moment of transition' (MT) i.e., the change from autonomous to manual driving, intervenes in human behaviour. These are combined with the analysis of the Smart Road, i.e., the street with innovative technologies that have the main purpose of reducing accidents and promoting road safety.

Keywords

Advanced Driver Assistant Systems, Visual Behaviour, ACC.

1 Methodology

The evaluation of road safety is related to two innovative instruments: the Mobile Eye Tracker, and the V-Box. The first is designed to monitor and gaze eye movements with two cameras mounted on special glasses; it provides the output of the movies with a red cross that focus on the driver's point of view (Figure 1. a). The V-box can monitor the kinematic parameters (e.g. speed, acceleration) and the position of the vehicle with a powerful GPS. Both instruments are used to identify the interaction between driver and vehicle and the driver and road, specifically the pedestrian crossing in Bologna (Fig 1. b). The first point of analysis considers the use of the Adaptive Cruise Control (ACC), an advanced driver assistance system (ADAS) that allows setting the distance from the previous vehicle, modulating the speed with the modifying of fuel flow and braking system [3]. The trend of speed and the point of view of the users allows evaluating the attention on the road scene and the impact of the ACC on driving behavior.

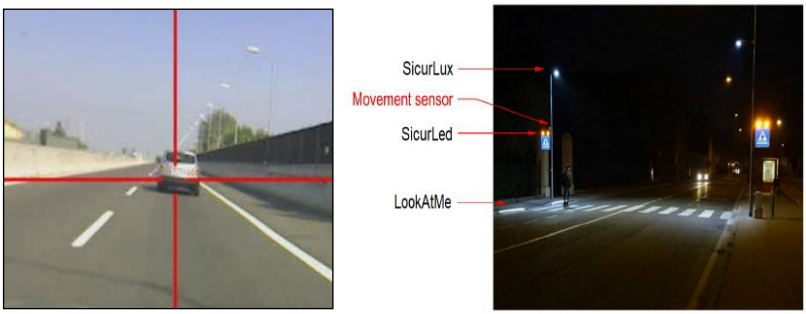

Figure 1. (a) The output of ME. (b) The innovative pedestrian crossing.

The second point highlights the interaction between the driver and the road, in order to evaluate the efficiency of the pedestrian crossing

in Via Andrea Costa (Bologna). It is characterized by several signaling systems controlled by pedestrian detection sensors or twilight switches and a video recording system, useful to analyze the behavior of drivers who approach the crossing [4].

2 Expected outcomes

The results obtained will be used to statistically quantify:

- the reliability of the tested ADAS;
- the effectiveness of the innovative system Sicur lux.

In particular, some important parameters will be extrapolated: the speed and position of the vehicle, the time of the first fixation and the average time of observation of the areas of interest, the scanning scheme (distribution of observation points) considering specific categories of attention and distraction. From these aspects, it will then be possible to highlight perception indicators, which relate the specifics of the element considered (geometry, appearance, location on the road) with the driving performance of users and with the new mechanisms introduced in the mechanics of the vehicle (ADAS) [5,6]. Each indicator will be parameterized for a definite category of users, type of road, and criticality identified in the path. In addition, it will be possible to evaluate the role of new Advanced Driver Assistance Systems in terms of attention and distraction and the impact of the new pedestrian crossing lighting system, according to specific comparisons of the driver's behaviour with the vehicle and roads.

3 Conclusions

The results will highlight the parameters considered suitable for road safety. Through a complete and exhaustive analysis of the vehicle-road-driver interaction, it will be possible to highlight the characteristics of the track and the most suitable technologies in order to reduce concretely the causes of the accidents.

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Pavement management system for local road administration: a tailored process for the Republic of San Marino

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Abstract

The research program aims to establish a tailored Pavement Management System (PMS) for Local Road Administrations (LRA), to plan activities, investments and to achieve efficient maintenance solution in a multi-year prospective.

In detail, this paper shows the principles, procedures and tools developed and used in the Republic of San Marino. At the beginning a rational, objective, and sustainable planning method (customized PMS) was identified, considering technical, economic, social and environmental impacts. Successively, Geographical Information System (GIS) tools and python routines were implemented and developed to support survey activities, ranking maintenance priorities and selection of cost-effective strategies.

Keywords

Pavement Management System (PMS), Local Road Administration (LRA), Geographic Information System (GIS)

1 Introduction

Given the increasing awareness of public opinion on social, economic and environmental impacts of road maintenance, Local Road Administrations (LRA) have realized the need to implement a systematic process of maintenance planning [1]. However, the implementation of the concepts and principles of the Pavement Management System (PMS) by LRA have to be reflected and customized according to the availability of each road authority in term of economic, human and technological resources, extent and heterogeneity of road networks. The evaluation of LRA real potential is essential for the definition of standard technical methods and procedures, plan activities and tools [2]. In this context, the use of Geographical Information System (GIS) can give great benefits due to the integration of road inventory data with graphical representation on thematic maps and spatial analyzing tools. For these reasons, GIS is one of the most appropriate tools to enhance data collection, set priority rating and support decision making [3].

The research project focused on implementation of PMS with the integration of GIS-based tools in the road network of the Republic of San Marino, in order to achieve an efficient and cost-effective maintenance planning.

2 Method and results

The implementation of PMS was designed as a self-feeding succession of connected phases, defined considering the specific needs and resources of the San Marino Road Administration, using tailored GIS-based tools and reference documents. Desktop and mobile applications were developed as shown in Figure 1 and Figure 2. The process was established on two operative levels: network level (knowledge of road information about whole road network) and project level (detailed considerations on specific road sections to support maintenance strategies).

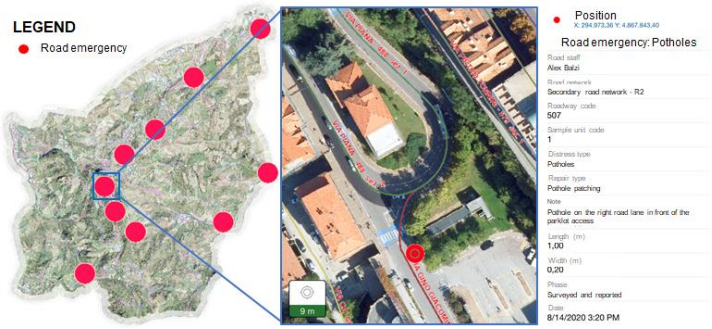

Figure 1. GIS-based mobile application for road pavement survey and monitoring

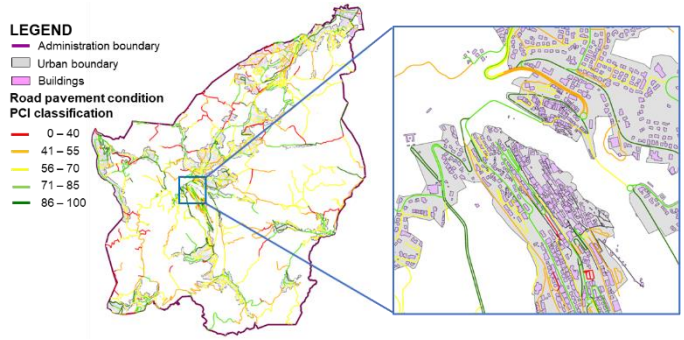

Figure 2. GIS map of the road pavement condition (Pavement Condition Index - PCI)

In detail, road network digitalization was performed on a dynamic GIS database, and the road network was classified and divided into network and road types, homogeneous sections and sample units according to specific characteristics: hierarchy, functional and traffic levels, urban or extra-urban context, geometric characteristics, pavement materials and courses, pavement conditions and rideability. The priority rating, maintenance strategies and analysis on evolution of pavement condition over time were performed by specific python routines on GIS database [5], [6].

3 Conclusions

The implementation of a tailored PMS in the Republic of San Marino has allowed to establish good practices and gather positive experiences [4], [5]. The use of GIS-based tools is particularly desirable for the standardization and rationalization of the recording, digitization and managing of road maintenance data.

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Developing a Life Cycle Management methodology for road pavements

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Abstract

The necessity of implementing sustainability is a main challenge in our society and it is taking up also in civil engineering works sector, although the infrastructure field is still understanding how to make the Sustainability Assessment (SA) a common practice within the National Road Authorities (NRAs).

This research aims at providing a specific methodology for the Life Cycle Management (LCM) of road pavements materials and activities, starting from the available ISO and EN standards, by using Life-Cycle based techniques and Multi-Criteria Decision Making (MCDM), with the aim of assessing performance under the three pillars of sustainability.

Keywords

Road Pavement, Life Cycle Sustainaiblity Assessment (LCSA), Building Information Modelling (BIM)

1 Methodology

SA is a more and more common practice, standardized at international and European level [1], although some gaps in methodology are still existing. This is what happens in road infrastructure sector, part of the so called "civil engineering works" [2] for which only a general standard exist. Hence, in order to try to fill this gap and propose a methodology for the LCM (SA + MCDM) [3, 4] for road pavements, the research has been articulated as follows:

1. Constant interaction with NRAs through workshops and questionnaires, so as to be aware of their needs and to increase their knowledge on the topic. This has been useful to define a specific set of indicators to calculate.
2. State-of-the-Art in SA, focusing on available standards and publications in literature. A fundamental role in this research have had the *Pavement Life Cycle Assessment Framework* [5] and the "Calculation methods" (EN 15978:2011) [6] for buildings.
3. Adaptation of European Standards to road pavements, adding than the MCDM. In particular, two standards have been mainly used: a) the EN 15978:2011 from which it was deduced a step-by-step procedure for the LCM of road pavements; 2) the EN15804:2011+A2:2019 [7] for the definition of a wider set of indicators and the methodology for the calculation.

2 Findings/Expected outcomes/Potential applications

On the basis of knowledge acquired through the research methodology described above, a step-by-step procedure for LCM has been defined [8].

The process is based on seven points and aims at helping NRAs in taking more robust and consistent choices throughout the life cycle of road pavement. In details:

- The first five points are equivalent to the first six ones in the standard. This part aims at defining the object of the assessment, the data collection and the impacts calculation (based on LCA and LCC) [9, 10, 11].
- The sixth step introduces the MCDM;
- The seventh step merges the last two steps of the standard, proposing report, communication and validation of results.

In order to facilitate the exercise, a specific framework [12] has been detailed as reference for the step 2, the so-called "object of the assessment". On the other side, it makes a difference between two systems: pavement materials (i.e. asphalt mixtures) and pavement activities (i.e. construction/maintenance of road pavements). They are different in terms of stakeholders involved (i.e. manufacturers or contractors/NRAs) and some specifics useful for the calculation (i.e. system boundaries, functional unit, etc).

Figure 3 – SA exercises for stakeholders working in road pavements sector [Lo Presti et al., 2021]

On one side, the framework contains the set of chosen indicators, aimed at calculating the environmental and economic burdens, plus the technical and functional requirements.

3 Conclusions

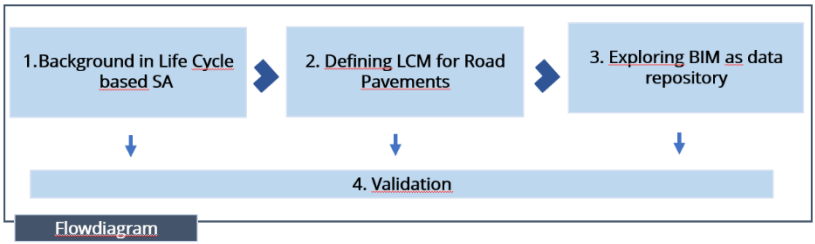
Starting from the need of making sustainability a robust and consistent practice within NRAs, the research aims at providing a Life-Cycle based methodology. In details, the following outcomes have been produced:

- A step-by-step procedure to perform the LCM(SA+MCDM) in road pavements sector;
- A Framework to guide the practitioners throughout the SA exercise, distinguishing two systems (pavement materials vs pavement activities) and providing a set of indicators specifically identified.

As next step, it is intended to implement also social indicators in order to perform a complete Life Cycle Sustainability Assessment to which apply the MCDM.

Furthermore, since data availability is a main factor for carrying out an LCSA, the research will explore the opportunities offered by Building Information Modelling (BIM) as repository for data.

Figure 4 - Research flowdiagram with next steps



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Effectiveness of reinforcement fibres in cold recycled asphalt mixtures

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Abstract

In the last decades, the cold recycling techniques have attracted more and more interest in the road sector, thanks to their important environmental benefits. Such materials, however, do not guarantee the same performance as hot mix asphalt, since they need 3–7 days of curing to develop a good early resistance, necessary for the reopen of road traffic [1]. Moreover, cold mixtures have lower fatigue resistance than HMA [2]. This research aims precisely to improve this property, going to insert synthetic fibres inside the mixture.

Keywords

Cold recycled asphalt mixture, fibres, SBS-modified bitumen emulsion

1 Materials and Methods

The objective of the study was the evaluation of the effect of synthetic fibres (a blend of aromatic polyamide, polypropylene monofilament and polyolefin) on the rheological properties and performance of cold recycled asphalt mixtures. Two different fibre

contents (0.05% and 0.1% by aggregate weight) were investigated and compared with a reference mix without fibres. Each mixture was characterised by the same gradation, same water content (5.0%), cement content (2.0%) and SBS-modified bitumen emulsion content (4.0%).

For each material, the Indirect Tensile Stiffness Modulus (ITSM) and the Indirect Tensile Strength (ITS) tests were conducted at 20 °C after 3, 7, 14 and 30 days of curing. Moreover, the Dynamic Modulus (DM) and the Indirect Tensile Fatigue (ITF) tests were carried out after 30 days of curing.

2 Partial Results

Figure 1 shows the results from ITSM (1a) and ITS (1b) tests at different curing times. It can be observed that ITSM and ITS increased with the curing time for all the materials. Between the mix with 0.05% fibres (F0.05%) and the reference mix, there was not a substantial difference in terms of stiffness and strength at the different curing times. Instead, the mix with 0.1% of fibres (F0.1%) showed lower ITSM and ITS values (about 15%) than the other materials at each curing time (except for ITS after 3 days of curing, which was similar between all the mixes).

Figure 2 shows the master curves of |E*| (2a) and phase angle ϕ (2b) at the reference temperature of 20 °C. It can be noted that at low frequencies / high temperatures the mix F0.05% had higher |E*| than the reference mix (about 35–40%). Instead, at high frequencies/low temperatures, the stiffness values were comparable. From figure 2b it can be noted that the mix F0.05% had lower phase angle at each frequency/temperature, denoting a higher elasticity.

The results from the ITF test at 20 °C were plotted in a bi-logarithmic graph showing the initial strain of the specimen as a function of the number of cycles (figure 3). The fatigue curve of F0.05% was above that of the reference mix. In particular, for each strain level, the mix with fibres allowed withstanding a higher number of cycles (almost

an order of magnitude) compared to the mix with no fibres. The tests on the mix F0.1% are still in progress.

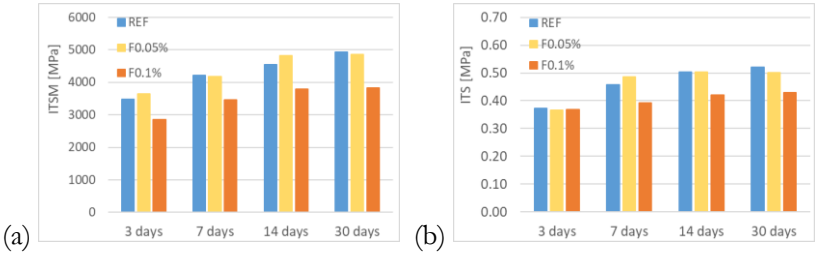

Figure 1. Results from ITSM (a) and ITS (b) tests

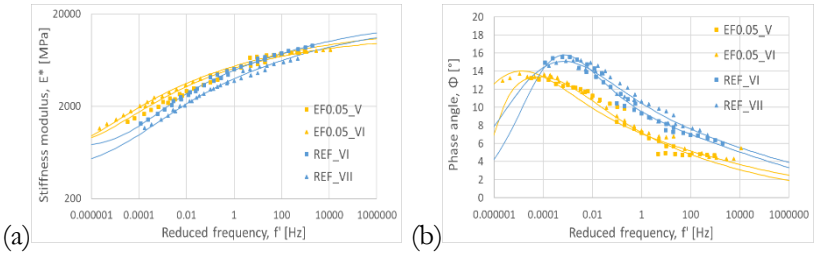

Figure 2. Complex modulus |E*| (a) and phase angle ϕ (b) master curves

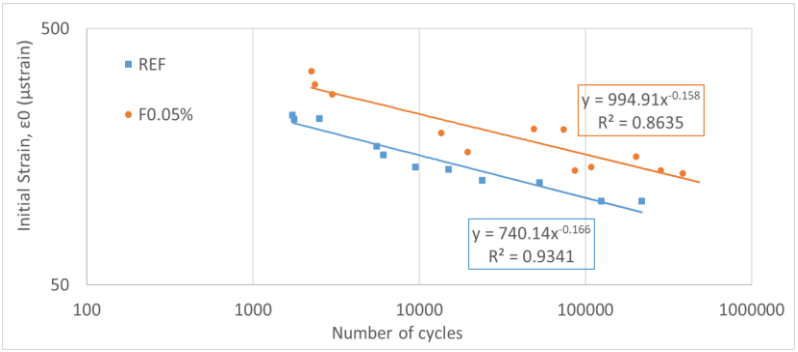

Figure 3. Results from fatigue tests

3 Conclusions

On the basis of the partial results, it is possible to conclude that the use of 0.05% of fibres in cold recycled asphalt mixtures determined an improvement of the performance in terms of stiffness, elasticity and, particularly, fatigue resistance. Subsequently, the contribution of a higher fibre content (0.1%) will be investigated both in terms of performance, but also with regard to the cost-benefit ratio.

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Laboratory investigation on WMAs for base layers with high percentage of RAP

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Abstract

Nowadays, the growing attention to the environment places Research in the road materials sector in front of new challenges. In fact, in the immediate future, it will be necessary to further decrease the use of raw materials (aggregates and bitumen) and the production temperatures of asphalt concrete to limit polluting emission. Reclaimed asphalt pavement (RAP) and warm mix asphalt (WMA) technologies have already been successfully used in road pavements, but the challenge now is to produce warm mixes with high percentage of reclaimed asphalt for high traffic volume roads, without penalizing mechanical properties.

In this regard, this manuscript describes a laboratory investigation involving WMAs for base layers containing 45% RAP. The experimental results showed that an adequate management of RAP allows to produce mixtures for motorway base layers with satisfactory mechanical and workability properties.

Keywords

Reclaimed Asphalt Pavement, Warm Mix Asphalt

1 Materials and methodology

The experimental investigation concerned three WMAs for base layers (DG45W_A, DG45W_B, DG45W_C) produced with three different percentages of total bitumen by weight of aggregates (4.2%, 4.4% and 4.6%, respectively) and containing 45% RAP. The mixtures were produced at 130 °C, by dosing a WMA chemical additive at 0.60% by weight of added virgin bitumen, and subsequently compacted at 120 °C. RAP best management practices have also been adopted to overcome technical and performance issues [1] for the subsequent production in asphalt plant. In fact, RAP was added to the mixtures in two distinct fractions, 30% RAP 8/20 plus 15% RAP 0/8, and the mix-design was also optimized using the Bailey Method [2].

The experimental program included about 60 tests overall. The volume of residual voids as well as the indirect tensile strength (ITS) were assessed to verify the requirements of Italian motorway technical specification. The Semi-Circular Bending (SCB) test, on the other hand, allowed to evaluate the fracture propagation resistance (K_{IC}) and the energy fracture (G) of the mixtures investigated. The Compaction Energy Index (CEI) [3] was calculated to study the compactability and workability of the mixtures. Finally, to allow the evaluation of the durability of the mixtures in terms of sensitivity to water, all laboratory tests were performed in both dry (72 h @ 25 °C) and wet (72 h @ 40 °C in water plus 3 h @ test temperature in air) conditions.

2 Findings

Figure 1 shows the main experimental results obtained for the three different mixtures tested.

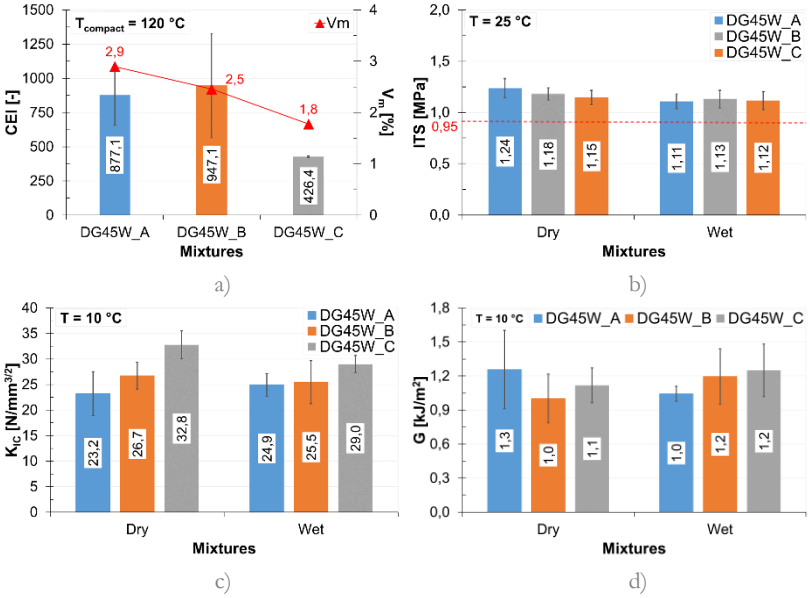

Figure 5. Main outcomes related to a) Compaction Energy Index, b) Indirect Tensile Strength (ITS), c) fracture resistance (K_{IC}), and d) fracture energy (G).

The analysis of the residual voids allows to state that the DG45W_A and DG45W_B mixtures comply with the technical specifications, as a percentage of residual voids greater than 2% at 200 revolutions is required for specimens compacted with a gyratory compactor (Figure 1a). Despite 45% RAP, the CEI parameter shows that all mixtures have good workability (Figure 1a), especially DG45W_A and DG45W_B. The high percentage of RAP does not even affect the ITS (Figure 1b), since the results comply the specifications requirements (ITS > 0.95 MPa). The parameters K_{IC} and G, on the other hand, show that the mixtures containing 45% RAP are not particularly brittle (Figure 1c), but sufficiently ductile (Figure 1d). In general, then, the total bitumen content does not seem to affect the mechanical properties of each mixture tested. Finally, it is worth noting that all mixtures show comparable mechanical parameter values for dry and wet conditions, therefore they are not negatively affected by water.

3 Conclusions

The experimental program carried out allows to state that WMA mixtures for base layers containing high percentage of RAP (45%) are able to meet the specifications required for traditional HMA, demonstrating the effectiveness of combining the WMA chemical additive, the aggregate gradation optimized through the Bailey Method, and the fractionation of RAP into several classes.

Based on the promising results obtained, the construction and subsequent analysis of a motorway field trial is planned, considering the mixture with the lowest total bitumen content (DG45W_A).

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Bio-binders for sustainable asphalt mixtures

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Abstract

One of the current main objectives of road pavements material sector is to replace bitumen with by-products deriving from renewable materials, thus promoting sustainability and circular economy principles. In this framework, plant-derived bio-oils and lignin can represent potentially attractive alternatives.

The experimental investigation carried out includes chemical and rheological analysis on two different bio-binders obtained by replacing 10% of bio-oil to a 50/70 plain bitumen and 30% of lignin to a 70/100 plain bitumen. Plain bitumens having the same consistency of the obtained bio-binders (i.e., 115 and 50/70 pen. grade respectively) have been selected by way of comparison. Moreover, a mechanical characterization including low, medium and high temperatures performances of the corresponding asphalt mixtures was performed. Promising outcomes encourage the feasibility of their use in asphalt pavements.

Keywords

Bio-binders, Bio-asphalt mixtures, Bio-oil, Lignin, Sustainability

1 Methodology

A rheological characterization of a previously optimized bio-binder containing 10% of bio-oil (coded as 50/70+A10) consisting in master curves and fatigue tests [1] was provided. Since the bio-oil addition causes a consistency reduction, a 115 plain bitumen characterised by a similar consistency was selected as reference. The same materials were used to produce asphalt mixtures with the same design gradation and binder content (5.8% by aggregate weight). Laboratory produced specimens were subjected to a conventional mechanical characterization (Table 1) [2].

Similarly, chemical and rheological analysis of the 70/100 plain bitumen blended with 30% of lignin (named 70/100_S30) consisting in SARA analysis and master curves were compared to a plain bitumen. Since lignin causes a consistency increase, a 50/70 pen. grade bitumen was selected as reference. Then, conventional and advanced (i.e., viscoelastic continuum damage model - VECD) mechanical characterization of the respective previously optimized asphalt mixtures containing 6.4% of bio-binder (4.6% of bitumen) and 5.4% of bitumen respectively, was performed.

Both unaged and long-term aged conditions of all materials were investigated. The experimental program is summarized in Table 1.

Materials	Binder Phase	Asphalt mixtures
50/70+A10	Master curves	Indirect Tensile Stiffness Modulus (ITSM) – 10-20-40°C
&	Fatigue	Indirect Tensile Fatigue Test (ITFT) – 20°C
115		Semi-Circular Bending (SCB) – 10°C
70/100_S30	SARA analysis	Indirect Tensile Stiffness Modulus (ITSM) – 10-20-30-40°C
&	Master curves	Indirect Tensile Fatigue Test (ITFT) – 20°C
50/70		Semi-Circular Bending (SCB) – 10°C

Table 1. Experimental program

2 Findings

Figure 1a shows that the bio-oil based binder offers a perfectly comparable complex modulus trend, as well as fatigue resistance [3] with

the reference plain bitumen selected, both in unaged and aged conditions. On the contrary, in Figure 1b the replacement of part of bitumen with lignin leads to a visible horizontal asymptote in the low frequency range, typical of bituminous mastics. It should mean that part of lignin probably acts like a filler, and part like a binder, as proved by SARA analysis. Results also show a higher stiffness, but lower aging susceptibility of the lignin-based asphalt binder compared to the reference plain bit.

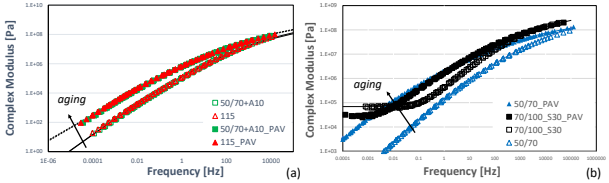

Figure 1. Master curves of the investigated bio-binders containing (a) bio-oil (b) lignin

From the ITSM test, the bio-oil based AM shows perfectly comparable stiffness properties with the reference one, while the lignin-based AM results stiffer than the reference M50/70 at all the investigated temperatures (Figure 2a), confirming what found at binder level. Moreover, M50/70+A10 shows similar thermal and aging susceptibility to the reference M115, while M70/100_S30 seems to be much less affected by temperature variations and aging effects than M50/70. As far as fatigue resistance is considered (Figure 2b), no substantial differences emerges when the bio-oil based AM is considered, especially in unaged conditions. Differently, a slightly reduced performance is attributable to long-term aging, which shows a higher slope of the fatigue envelope. The opposite trend is observed for M70/100_S30. Moreover, results deriving from conventional mechanical characterization on lignin-based and respective reference 50/70 AM were further validated by test conducted on the same materials following the more advanced VECD method. Finally, from the thermal cracking showed in Figure 2c, the bio-oil based AM showed higher fracture toughness in unaged conditions, but the higher resistance is not confirmed after aging. On the contrary, lignin seems to have a positive effect on AM after aging.

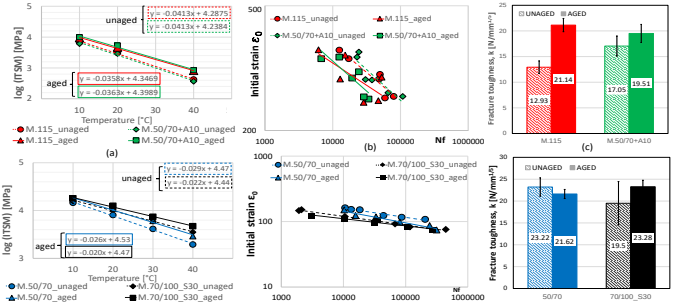

Figure 2. Mechanical characterization of bio-based AM in terms of (a) ITSM, (b) ITFT, (c) SCB

3 Conclusions

Overall, rheological and mechanical characterization of AMs show promising results since no significative differences are highlighted between the selected bio-binders and the conventional reference ones. These findings encourage the use of such bio-binders in asphalt pavements, meeting the sustainability and circular economy principles.

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Analysis of interaction mechanisms between regular vehicles and autonomous vehicles for road safety purposes

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Abstract

Technological innovations have a great impact on the world of infrastructures. The introduction of connected and automated vehicles (CAVs) will significantly change the way roads are conceived. At the same time, the idea of road safety may also be completely reshaped. The research activity is aimed to analyse the interaction between traditional vehicles and CAVs and the driving environment, to make the infrastructure more intelligible to CAVs and to analyse the impact on road safety. Safety performances will be analysed in two phases, one relating to the simulation of future scenarios through traffic simulators [1], and the other relating to the validation of the traffic simulator outputs through the use of driving simulators or real road tests [2].

Keywords

Autonomous vehicles, Road Safety, Traffic Simulators

1 Methodology

In order to define road safety improvements, we refer to the definition of Safety Performance Functions (SPF) [3]. SPFs can be adapted to other similar scenarios through the use of CMFs (Crash Modification Factors). There are currently few examples of SPFs or CMFs specifically developed in literature to take into account the increasing presence of CAVs. For a correct road safety assessment in

such environments, specific functions must therefore be studied. For this reason, since adequate crash data is not available, simulation methods must be used. This purpose might be pursued thanks to the use of specific traffic simulators whose results must be validated through driving simulators.

2 Findings/Expected outcomes/Potential applications

A case study of road safety analysis after the implementation of CAVs was run on the provincial roads of the Metropolitan City of Bari. In detail, the evaluation of driving environments with the presence of CAVs was carried out by analysing two different aspects: traffic macro-indicators (waiting times, volumes, density, average speeds), analysed with the AIMSUN traffic micro-simulator [4]; traffic safety (collisions and conflicts), analysed with the SSAM (Surrogate Safety Assessment Model) software [5]. In order to assess the impact of the fundamental parameters considered by the micro simulator in terms of road safety, it was deemed appropriate to carry out a sensitivity analysis. Each parameter was set with a different value one per time with ceteris paribus. The analysis was carried out on a sample of 8 roads with different characteristics and traffic in order to understand how these parameters could influence the results recorded.

The outputs of the traffic microscopic simulations include the trajectories of vehicles, which can be used for safety assessment purposes. In particular, the SSAM software is among the most used for those evaluations [7]. The SSAM has been widely validated by comparing simulated results with observed crash data [6]. The SSAM software calculates surrogate indicators of road safety and identifies possible collisions. The indicators that the SSAM software evaluates are Time To Collision (TTC); Post Encroachment Time (PET); Initial Deceleration Rate (DR); Maximum speed of the two involved vehicles (MaxS); Maximum relative speed of the two involved vehicles (ΔS). The threshold values for defining a collision (TTC and PET) and identifying its severity (DR, MaxS and ΔS) are as follows:

TTC (s)	PET(s)	DR (m/s)	MaxS (m/s)	ΔS (m/s)
1,5	5	-13,17	16,10	33,65

Table 1. Threshold values identify by SSAM software

The sensitivity analysis, comparing different scenarios with regular vehicles and CAVs, produced the following results. For crossing collisions, the most influential parameters are: look-ahead distance factor (-28%); maximum desired speed (-28%); speed limit acceptance (+44%); clearance (-26%). For rear-end collisions, the most influential parameters are sensitivity factor (+37%); gap (+36%); maximum yield time (+33%); clearance (-32%). For the lane-changing collisions, the most influential parameters are: normal deceleration (-33%); overtake speed threshold (+36%).

In the future, the SPF [7] for autonomous and conventional vehicles will be defined. Based on the information provided by the SPFs, different scenarios with different changes in the current road geometry will be assumed to improve road safety. A sensitivity analysis of the geometric variables will be carried out in the first instance, followed by new traffic simulations. The effects of these changes will be assessed by comparing the previously calculated road safety indicators with those calculated after the change. Starting with the results obtained from the traffic simulations, it is planned to compare them with results obtained from driving simulators or road tests. The driving simulator (or road test) is focused on the behaviour of the individual vehicle and its interactions with the surrounding environment, which may highlight critical points overlooked by previous analyses. The possible confirmation or addition of new criticalities based on these simulations would allow the refinement of the SPFs so that they include all the relevant variables.

3 Conclusions

The present research aims to provide an analytical and technical tool to answer to the problem of crashes prediction in presence of

different market penetration rates of CAVs. One strict necessity is to obtain through the simulations more robust crash frequency estimates to respond to the growing automation systems in the vehicle fleet; another crucial aspect is to verify the possible effects of traditional drivers on driving behaviour in the presence of CAVs.

These are ambitious goals that the current research does not claim to solve but in respect of which it wants to contribute.

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Evaluation of failure behaviour of cold recycled material mixtures

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Abstract

In recent years, the need to adopt economical and environmentally sustainable pavements construction technologies is growing more and more. Cold recycled material (CRM) mixtures are an eco- friendly material which is produced at ambient temperature, employing the bitumen in form of emulsion or foam, significantly limiting the carbon footprint [1].

However, at the current state of the knowledge, the structural design of cold recycled pavements, is carried out using empirical methods. The aim of this Doctoral programme is to contribute to the use of CRM mixtures in mechanistic-empirical design methods. In this context, in order to fill a knowledge gap, this research aims at improving the investigation of the CRM mixtures failure behaviour, which is a key input for mechanistic-empirical pavement design procedures.

Keywords

Cold recycled materials, fine aggregate matrix, fatigue behaviour, bitumen emulsion

1 Methodology

To study the fatigue behaviour of CRM mixtures, a multiscale approach is used. It is based on the design and testing of fine aggregate matrix (FAM) mortars. In fact, at the mixture scale, CRM can be considered a particulate composite where coarse aggregate particles (inclusions) are dispersed in the FAM phase. Several studies have shown that FAM properties affect the viscoelastic, fatigue and fracture behaviour of asphalt concrete mixtures [2].

In CRM mixtures, the coarse aggregate consists of RA. The FAM is a mortar composed of fine aggregate, filler, bitumen and voids. The objective is to investigate the fatigue resistance of the FAM and compare it with that of the mixtures.

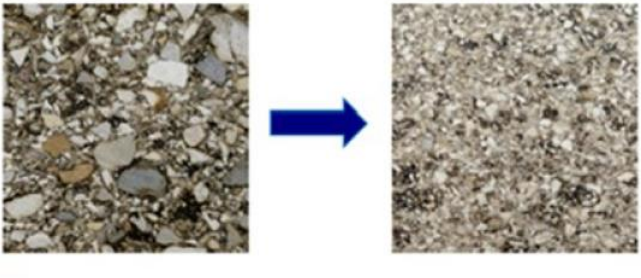

Figure 1. *Mixture vs Mortar (macroscale)*

As materials, CRM with bitumen emulsion will be investigated. The RA content will be higher than 80% to ensure high environmental and economical sustainability. As for binders, the mixtures will be produced with a bitumen emulsion content that ranges between 3,0 and 5,0%, while for the cement, the range is between 1,5 and 2,5%.

2 Expected outcomes and potential applications

The main goal of this Doctoral programme is to be able to use CRM in in mechanistic-empirical design methods. To do this, the study of fatigue behaviour of CRM will be treated both with the traditional approach, which consists in the construction of fatigue curves, and with the viscoelastic continuous damage (VECD) approach.

Based on previous studies, it has been seen that FAM is used to predict the overall behaviour of the CRM mixture using multiscale models. The focus will be mainly on:

- Construction of fatigue curves on FAM mortars that are more homogeneous than mixtures and contain the binders;
- Evaluation of the effect of two experimental variables such as temperature and voids on CRM;

Moreover, a further objective is to investigate the failure behaviour of CRM mixtures and FAM mortars on small scale specimens (D_{max} = 38 mm). In a previous study, complex modulus tests have been carried out to assess the effect of the specimens geometry on the measurement of the stiffness behaviour of CRM mixtures [3]. Figure 2 shows that the stiffness modulus of 38 mm specimens was comparable with that of 75 and 100 mm.

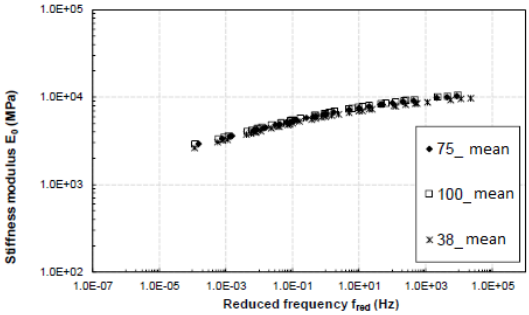

Figure 2. *Mastercurves of specimens with three different diameters.*

3 Conclusions

The main goals of this Doctoral programme can be summarized as follow:

- To investigate the failure properties of CRM mixtures on FAM mortars following the traditional and VECD approaches;
- To evaluate the potential application to the use of CRM in mechanistic-empirical design methods.

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Waste cigarette filters as fibres in asphalt mixtures

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Abstract

This research aims to explore the possibility of using waste electronic cigarette filters (E-CFs) as fibres to improve the stabilizing effect and mechanical properties of asphalt mixtures. To achieve the objective, shredded waste E-CFs were incorporated in Stone Mastic Asphalt (SMA). Drain-down tests were conducted to determine the most appropriate dosage and the absorption properties of waste E-CFs. SMA samples with waste E-CFs and conventional cellulose fibres were produced and analysed via physical and mechanical tests. The results of this study are expected to identify a sustainable and environmental alternative to the common disposal of cigarette butts.

Keywords

Fibres, waste cigarette filters, SMA, drain-down test

1 Methodology

Different fibres are widely used in asphalt pavements to achieve stabilizing or reinforcing effects. The commonly used fibres include cellulose, coconut, mineral, carbon, polyester, and polypropylene fibres [1]. In line with the increasing sustainable and environmental approach to pavement engineering, recycled and waste materials have been increasingly introduced into pavement constructions, including waste fibres. The possible use of waste fibres obtained from waste tires and carpets, nylon wires, and cigarette butts (CBs) have been explored by different researchers [2-6]. In terms of waste CBs, studies from Mohajerani et al. [4, 5] presented their successful use as a replacement for coarse aggregates and bitumen modifier. Another study from Tataranni and Sangiorgi proved the potential use of new electronic cigarette filters (E-CFs) as a sustainable alternative for cellulose fibres in Stone Mastic Asphalt (SMA) mixtures [6]. To verify the recycling of waste E-CFs in asphalt mixtures and find an environmental-friendly alternative to their disposal, this paper focuses on the experimental investigation of waste E-CFs in SMA.

The waste E-CF consists of cellulose acetate fibres, plastic, tobacco ashes, plug wrap paper and tipping paper (Figure 1). By means of a mechanical shredder, waste E-CFs were ground into particles with the size below 10 mm and used as fibres in SMA. A second SMA with the same aggregate gradation, bitumen type and dosage but made with traditional cellulose fibres was used as control mixture. In the mix design, a gap-graded gradation (12 mm maximum size of aggregates) and polymer modified bitumen Pen 45/80 (6% by weight of aggregates) were used. Tests including drain-down test (ASTM D 6390-11), air voids content (EN 12697-8), static and dynamic mechanical tests were conducted to verify the effect given by the substitution of cellulose fibres with waste E-CFs. Specifically, mechanical tests included Indirect Tensile Strength (ITS, EN 12697-23), Indirect Tensile Stiffness Modulus (ITSM,

EN 12697-26), and Indirect Tensile Strength Ratio (ITSR, EN 12697-12).

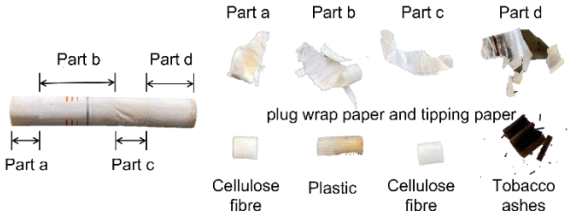

Figure 1. Detailed components of a waste E-CF

2 Findings/Expected outcomes/Potential applications

From drain-down results, the two selected dosages of waste E-CFs (0.3% and 0.4 % on aggregates) showed absorption properties comparable to the cellulose fibres (drain-down value below 0.3 %). Hence 0.4 % was identified as the optimal dosage of waste E-CFs. From physical and mechanical test results (Table 1), SMA with waste E-CFs shows similar workability and compactability properties. Though lower stiffness and cohesion property was found for waste E-CFs mixture samples, the negative effect is not significant. Waste E-CFs led to lower water susceptibility than cellulose fibres.

Properties		Waste E-CFs	Cellulose fibres
Air voids content (%)		2.4 (±0.1)	2.7 (±0.2)
ITSM (MPa)	@10 °C	7202	8547
	@20 °C	3641	4188
	@30 °C	1381	2172
ITS (MPa)		1.25 (±0.05)	1.40 (±0.07)
ITSR (%)		105	95

Table 1. Physical and mechanical properties of SMA with different fibres

3 Conclusions

Based on the conducted experiments, the utilization of waste E-CFs in SMA mixtures can be considered as a promising alternative for replacing cellulose fibres and avoiding the disposal of cigarette butts. The discarding of plastic particles from shredded E-CFs might improve their performance as fibres.

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Repairing road pavement potholes with cold mix patching materials

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Abstract

Cold mix patching materials (CMPMs) are commonly used as an alternative to hot mix asphalt to repair road pavement potholes and localized distress. They are affordable, have a short application time, and have lower environmental impacts. Despite the advantages of CMPMs in treatment operations, they have relatively poor performance and durability, especially in cold weather conditions. Although high quality CMPMs show better performance, there are no accepted test methods and standards to evaluate the quality and performance of these materials. In this study, CMPMs were analysed and their use, performance, and methods of evaluation were investigated. Also, proposing new test methods to investigate CMPMs' characteristics was considered.

Keywords

Pothole, Cold patch, Road maintenance

1 Introduction

Potholes are one of the most common types of road pavement distress, which expand quickly during the winter and spring seasons. They should be repaired as soon as possible to restore the serviceability

of the pavement and create a safe surface for all road users. [1]. In recent years, cold mix patching materials (CMPMs), due to their cost-effectiveness, ease of handling, few labour requirements and equipment, less environmental impact, and longer storage time, have become popular for repairing potholes, especially in the cold seasons [2]. Although CMPMs have a short application time, they are the lowest quality of all patching materials. These materials are associated with poor bonding, ravelling, water sensitivity, poor workability and stability. However, if the CMPM used to repair potholes is a high-quality material, it can last longer. Hence, there are no accepted test methods in the literature to assess CMPM characteristics and determine their quality. This study focused on analysing CMPMs, their evaluation methods, and proposing new test methods to investigate CMPMs' characteristics [3].

2 Cold mix patching materials

CMPMs are composed of a mix of aggregates with special binders and additives. The dosage and type of the ingredients in the mix design can affect CMPMs major issues such as their workability and stability. A soft binder with low viscosity is needed to provide satisfactory workability; however, for better cohesion and stability of the patch, high binder viscosity is preferable. Also, to achieve better stability, a high degree of aggregate angularity is required, even though angular aggregates do not provide good workability. Therefore, precautions should be considered to strike a balance between the ingredients in the mix design [4].

3 CMPMs application methods

Pothole repair operations include several temporary and semi-permanent to permanent approaches [5]. However, CMPMs are usually applied in an emergency situation as a temporary treatment until proper and definite practice is conducted. Temporary repairs for applying CMPMs are as follows;

Throw-and-go: The cold mixture is just shovelled into the pothole without any heavy compaction and removing the water and debris. The patch is compacted by normal traffic.

Throw-and-roll: The cold patch is placed into the unprepared pothole and compacted using a hand tamper and the truck tires.

Edge seal: The repair method is similar to throw-and-roll, but after compaction, the perimeter of the repaired section is covered with a tack coat and sand. Then, it is left for about one day to dry.

4 CMPMs performance evaluation

Patch failures are often due to the lack of desirable characteristics. Thus, the evaluation of the mixture properties can help to understand which types of materials deteriorate in a short time and are not suitable for use in the field. CMPM properties are engaged with each other and the durability of the mixture is achieved under their overall performance. Since there are abundant materials on the market claiming to have the best performance, the only way to assess their properties is through laboratory experiments along with a long-term field study. The field performance is usually carried out through visual evaluations by engineers. However, the laboratory tests are more quantitative. Hence, in the literature, no strong correlation was obtained between laboratory and field results. Therefore, utilized laboratory tests may such as Marshall stability and ITS may not reflect the characteristics of CMPMs.

5 Conclusion

CMPMs are quickly developing for patching potholes as suitable alternatives to HMA. However, there are still some limitations and issues with their mix design and performance evaluation. The performance evaluation approaches do not always meet the requirements of CMPMs. Also, there is a conflict between mechanical performance, which is required in the field and the easiness of application and compaction that

is demanded by road maintenance operators. Therefore, developing new procedures that can evaluate the performance of these kinds of materials is essential.

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BIM Workflow for Stone Pavements

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Abstract

Building Information Modelling (BIM) integrates many technologies and practices that bring digital tools and a data-centric approach for improving lifecycle delivery and management of infrastructure assets.

However, much remains to be done for the development of the methodology with regard to the specific case of stone-paved roads.

In light of this, the purpose of this research is to bring attention to the importance of roads digitalization with stone-paved surfaces, by the development of a general methodology for data collection, processing, and management, based on BIM and methods for procedural automation.

Keywords

BIM, Stone Pavements, VPL scripting

1 Methodology

The proposed methodology consists of three core zones as shown in Figure 1: Data Collection, Data Processing, Modeling Phase.

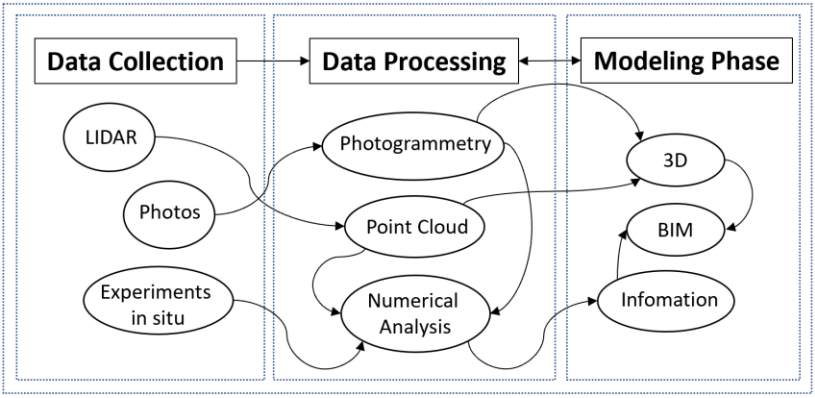

Figure 6 – Methodology Workflow.

In the first phase, on-site survey operations were carried out with the use of photographic survey [1], 3D Laser measurements [2], and pavement surface testing [3].

Data collected were then processed to produce digital media for the calculation of a variety of characteristics. For example, by means of laser scanning, it is possible to obtain one or more point clouds representative of the scanned environment [2]; by means of photogrammetry, it is possible to obtain the 3D representation, both in the form of mesh and point cloud, of the photographed object, with a very high level of detail [1]. Other tools are used for the collection of descriptive data on the surfaces or unknown stratigraphy of roads, to be analysed numerically and statistically [3].

Based on the use of available commercial BIM-based tools, the modelling phase was carried out in the following steps: 1. creation of the Digital Terrain Model (DTM); 2. creation of the horizontal alignment

and the vertical profile; 3. creation of the parametric and customised cross-section; 4. creation of the road corridor; 5. Creation of the informative model; 6. use of scripts in Visual Programming Language for updating the databases and numerical analysis.

2 Findings

- The survey techniques used mainly concern the geometry and surface of the roads; information on the construction materials used can only be found by inferring them from non-invasive tests, and thus only indirectly;
- The models produced are mainly used as databases, due to an inherent limitation of the research. In fact, there is no commercial software currently available that is prepared for modeling stone-paved roads (usually historical). This means that the aesthetic rendering is not precisely representative of the state of the asset, that is instead left only to descriptive data within the model.

3 Conclusions

The aim of this line of research is the integration of BIM and the disciplines of pavement engineering, in order to improve the management and preservation capabilities of stone-paved road assets, developing maintenance plans and intervention strategies, by means of reliable databases and digital models.

So, future research should consolidate and extend workflows that implement process automation within models, and it would be crucial to develop dedicated software for the particular kind of roads of interest, and to find data collection techniques to improve the quality and quantity of data.

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Exploratory analysis of electric scooter crashes in the City of Bari

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Abstract

The diffidence towards collective transport following the pandemic period, together with technological advances, accelerated the shift from traditional means of transport for urban routes in favour of new vehicles such as e-scooters. Consequently, the road safety analysis of e-scooter mobility is urgent. The aim of this research in the road safety field is to understand the problems associated with the use of these vehicles and identify the most frequent ones. The starting point of this research is the analysis of a crash database provided by the Local Police of the City of Bari. The crashes recorded in the urban area of the City of Bari involving e-scooter were 166 for the period May 2020 – December 2021. The most frequent crashes are angle crashes (23%). Although crashes are divided almost equally between segments and intersections, the most common type is the angle crash, which prevails at intersections. On two-lane segments, the most common type is the sideswipe, which, however, is frequent at intersections as well.

Keywords

Micro-mobility, Road safety, Smart mobility

1 Methodology

The most important goal of this research is understanding the safety issues encountered by people driving e-scooters. Because it is a relatively new mean of transport, the problems connected to it are still unknown. The first step of this study adopts a methodology based on e-scooter crash data stored by the Local Police of the City of Bari [1], accounting for a total of 166 crashes in the period May 2020-December 2021. Local police data guarantee greater accuracy because they also include property damage only crashes. The aim is to analyse crashes in detail [2] and find patterns to understand the causes and factors with the greatest impact on the crash phenomenon.

In the future, the aim is to develop a predictive model and so the study of the actual data collection is necessary for the research. Data are very recent, thus one of the next steps of the research is to compare these data with the e-scooter traffic volumes of the last two years (they started to become popular in the City of Bari in 2020), to obtain crash rates.

2 Findings/Expected outcomes/Potential applications

The database provides the following crash information: date, time, type, type of vehicles involved, location, injuries, type of traffic violation.

Figure 1: Geolocalisation of crashes (different colours are for different crash types)

Figure 2 shows the results of the analysis, illustrating which crash type happened most frequently and splitting the crashes into those occurring on segments and those occurring at intersections.

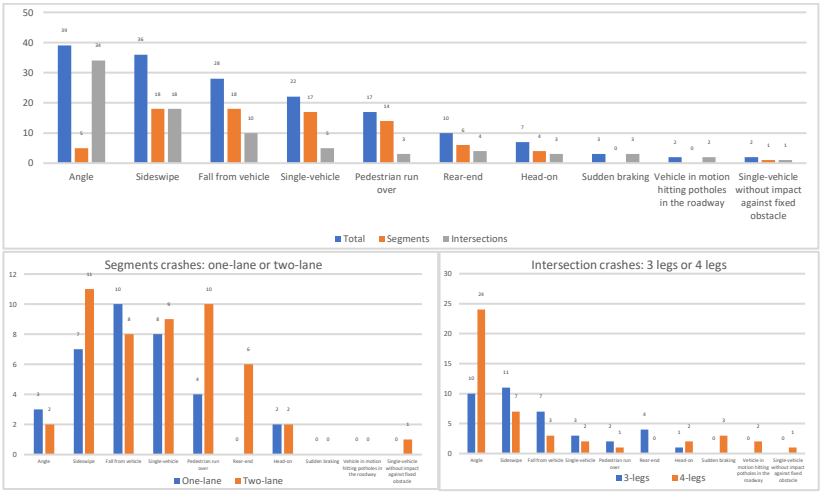

Figure 2- Results from the analysis of segment and intersection crash types

This analysis shows that 23% of crashes occurred as angle collisions. As well as crashes with cars [3], this type of crash happens mainly at intersections, where the e-scooter is exposed to dangerous situations, since it takes a long time to cross the intersection, and because of its small size and low speed. Another frequent type of crash is sideswipe (22%), which take place especially because e-scooters move in a mixed traffic, but without driving assistance systems such as rear-view mirrors and with speeds largely different than other vehicles that cause overtaking situations, leading to side collisions. Fall from vehicle also constitutes a large proportion of crashes (17%) and can be due to the condition of the road surface, or vehicle issues and driver distraction [4].

As expected, among all the crashes recorded, most crashes occurred during summer and daylight. This aspect will be further investigated when these data will be compared with the traffic flow

volumes of scooters to determine crash rates. The analysis conducted represents only a first step for a future research project, so the goal is to discover the relevant issues of e-scooter traffic circulation, aiming at the development of prediction models, such as e.g., Safety Performance Functions (SPFs) for crashes to e-scooters and other micro-mobility means of transport. The final aim is to correlate infrastructural and non-infrastructure-related criticalities with crashes and to be able to draw up appropriate mitigation strategies and/or relevant policies.

3 Conclusions

This research wants to provide an initial analytical and technical tool to give answers to the problem of crashes in relation to micro-mobility. Therefore, it is essential to study segments and intersections for modelling crashes and linking them to specific geometric parameters and find common trends and/or significant differences with the aim of finding the appropriate countermeasures and/or promoting specific traffic policies. This is a first approach that certainly needs more in-depth studies, especially depending on when e-scooter data will be available for a longer period.

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Promoting the use of alternative materials in Italian road pavement by introducing performance related characterisation

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Abstract

The increase in traffic volumes in the road infrastructure and the constant action of atmospheric agents, accelerate the deterioration of road pavements and decreases the level of performance in operation. In addition, the steadily increasing trend in the use of alternative materials (e.g., tyre rubber) as the main component of asphalt mixtures leads to an engineered design based on the expected performance of the material in the field. However, the Italian specifications [1] are mainly based on voids control, volumetric and strength properties, without considering important features like stiffness, permanent deformation resistance or fatigue behaviour [2]. Hence, this work is a piece of a bigger project that, wants to be a first step towards introducing Performance-Related Characterisation (PRC) at different traffic levels and operative temperatures, with the objective to improve the current Italian procedure. The experimental programme includes a case study that presents a basic-level comparative analysis of two asphalt mixtures for low-traffic volume wearing courses: a conventional mixture wearing course and an adaptation of the mixture with engineered crumb rubber (ECR) by the dry process [5]. As result, this work wants to highlight how the proposed PRC-basic level methodology could be implemented in Italian specifications to move acceptance criteria towards performance-based properties.

Keywords

Performance related characterisation, rubberised asphalt mixture, pavement materials, sustainable pavements, dry process

1 Methodology

In this study the experimental program (figure 1) includes a performance characterisation with the aim of introducing modified rubber mixtures on Italian roads.

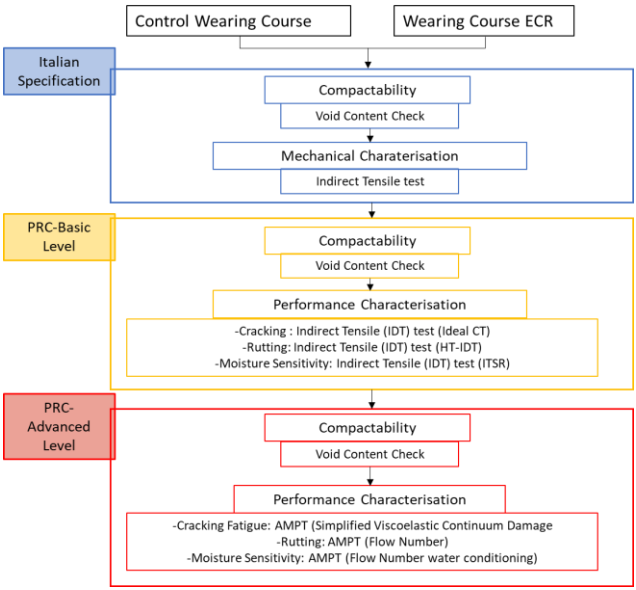

Figure 7. Experimental Programme

A comply with Italian road authority was and a basic level performance characterisation was carried out as a first step (blue and orange in figure 1), but the future objective will be to study the viscoelastic properties of the material with an advanced performance characterization as shown in figure 1 in red colour. Performance-related

parameters and the target values, for this research, have been identified through a literature review. While Italian road authorities require conventional target such as Indirect Tensile Strength (ITS) and Coefficient Indirect Tensile (CTI) [1], the proposed performance characterisation Basic Level includes the following parameters obtained from the Indirect Tensile Strength: 1) Cracking: Indirect Tensile (IDT) test (Ideal CT) with conditioning temperature of 20±5°C for between 48 h and 42 d [3]; 2) Rutting: Indirect Tensile (IDT) test (HT-IDT) with conditioning temperature of 50±1°C for 2hours±10min [4]; 3) Moisture Sensitivity: Indirect Tensile (IDT) test (ITSR) with conditioning temperature of 40±2°C for 72±2h.

Tests related to mechanical and performance characterisation were carried out at different temperatures to describe the different damage phenomena.

2 Findings/Expected outcomes/Potential applications

The main findings are show in Figure 2 and as follows:

- Reference Mixture met the road authority requirements in terms of air voids requirements (linked to compactability) and indirect tensile strength (ITS);
- All the considered mechanical parameters are similar between control and when ECR is incorporated;
- All ECR mixtures are in compliance and present a slight improvement when compared with conventional mixtures in terms of performance related to cracking and moisture sensitivity but much higher in terms of rutting.

TESTS		Wearing course Control	Wearing course ECR
Compliance with Italian Road Authority	Indirect Tensile Strength (ITS) (MPa)	=	=
BASIC LEVEL	Cracking: Indirect Tensile (IDT) test (Ideal CT)		+
	Rutting: Indirect Tensile (IDT) test (HT-IDT)		+
	Moisture Sensitivity: Indirect Tensile (IDT) test (ITSR)		+

Figure 8. Wearing course control VS Wearing course ECR

3 Conclusions

The compliance to the Italian road authority requirements and the performances of the materials in terms of cracking, permanent deformation and moisture susceptibility resistance were assessed, proving that rubberised asphalt mixtures complied with Italian requirements and that provide enhanced performance rather conventional mixtures. The authors will continue the work with further laboratory testing looking also at a more advanced performance-related characterisation, for instance looking at visco-elastic properties of the material by means of the Asphalt Mechanical Performance Tester [6], present within the Engineering Department of the University of Palermo. This is deemed necessary to highlight benefits of unconventional asphalt mixtures especially for roads with high traffic volumes.

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An automatic pothole detection algorithm using pavement 3D data

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Abstract

Road surfaces are subject to various forms of degradation that compromise their functionality with negative effects on safety. Beyond the various studies available in literature for the different forms of distresses, in this research the authors propose an innovative method to detect and identify surface potholes by exploiting 3D data. In particular, the proposed algorithm relies on the elaboration of 3D images of the pavement surfaces, acquired by a high-performance instrumentation. The algorithm, derived from the computer vision protocols, is able not only to reliably identify potholes and measure their areas, but also to evaluate their depth. The numerical results show the remarkable performance of the proposed approach, representing a reliable improvement to traditional methods.

Keywords

Pavement potholes, automatic distress detection, 3D data, pavement quality, computer vision.

1 Methodology

The proposed methodology aims to identify and characterize road potholes. On the basis of the detection techniques already existing in the literature, namely vibration analysis and 2D and 3D image analysis techniques [1], an algorithm for the automatic pothole detection has been developed not only in terms of surface but also of depth, which allows to process 3D data starting from a plane representation of the image: the pothole is detected and geometrically characterized on a 2D plane, assimilating the light intensity scale of digital images to the elevation map of the 3D image. This was possible thanks to the detail of the images acquired by an innovative instrumentation for the automated survey of road surfaces in 2D and 3D mode, HiPROSS (High Performance Road Survey System), developed at the University of Messina [2]. The proposed procedure is characterized by five different phases, as shown in Figure 1:

1. Preprocessing: the 3D image is pretreated (a) and transformed into a binary image (b), to reduce its complexity.

2. Segmentation: the potholes are separated from other possible defects (eg cracks), identifying the area where there are lower altitudes, excluding all the rest (background) (c). A semantic segmentation is applied that takes into account the intensity scale which, in this case, corresponds to the different floor heights.

3. Image post-processing: morphological and connectivity operations are applied through processes of dilatation and active contours, to refine the contours and to eliminate false positives (d).

4. Geometric properties: the pothole geometrical information is calculated, first of all perimeter and area.

5. Depth: the maximum depth is calculated and the transverse and longitudinal profiles are drawn along main axes (e).

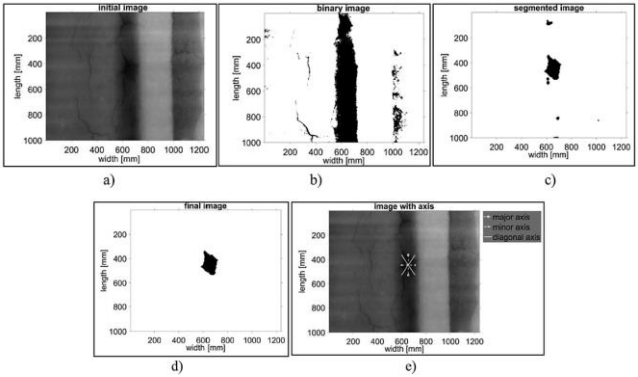

Figure 1: Steps of the procedure: (a) initial greyscale image; (b) binarized image; (c) segmented image; (d) improved final algorithm image; (e) tracing of principal axes

2 Findings/Expected outcomes/Potential applications

Through a specific MATLAB routine, the algorithm was tested on 50 images, of which 44 contain one or more potholes, with different morphological and elevation characteristics or other defects, while 6 do not contain potholes, to check for false positives. For each image, the algorithm provided geometric and depth data.

The results obtained were validated through quality and precision tests. First, a pixel-by-pixel statistical evaluation of the results was performed, both through the comparison with the ground-truth image, using the metrics of the confusion matrix, but also by calculating the error rates of the detected area; Finally, numerical comparisons were made, in terms of area, with some traditional edge detection methods, further highlighting the algorithm's effectiveness. The comparison results are summarized in Table 1. The feedback obtained from these checks can be used to classify potholes for project-level maintenance analyzes or even for safety assessments for 2-wheelers.

Method	Precision	Recall	F-Score	Area Error Rate
Proposed procedure	**89,75**	**92,95**	**91,28**	**5,15%**
Sobel	74,23	69,24	68,52	12,65%
Canny	61,00	71,01	60,86	21,40%
Prewitt	74,06	69,22	68,54	12,89%
Roberts	75,26	67,87	68,06	12,77%
Log	61,95	70,80	60,43	20,30%

Table 1: Summary of comparison values for the compared methods

3 Conclusions

In this study, a procedure for automatic pothole detection through the processing of 3D images of road pavement surfaces is proposed. The algorithm may effectively identify 3D features of potholes, excluding false positives or other forms of irregularities, in an automatic approach, producing consistent results on various types of images. The potential of the algorithm represents a valid support to the road safety maintenance and management processes and allows it to be perfectly combined with other automatic detection procedures (for example for cracks or rutting).

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Innovative methodologies to evaluate project scenarios on cycle-pedestrian networks

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Abstract

The Canal Port of Rimini is a great historical and cultural relevance site representing an urban landmark for the city. At present it is undervalued and poorly linked to the existing urban context. Adequate infrastructure, comfortable transport, safe places and easy access for weak users are key to upgrading urban areas and facilitating sustainable mobility [1]. The present research aims to demonstrate that re-shaping the existing infrastructure network, which represents key role in the interconnection and continuity of the urban landscape, would allow the regeneration of the urban area without changing its historical structure. In addition, it will show how improvements in the cycle network and micro-mobility, along with punctual regeneration interventions, also contribute to improving the life quality and comfort of the surrounding area.

Keywords

Cycle-pedestrian networks, ANP-BOCR analysis, Virtual Reality Model

1 Methodology

The redevelopment of the urban area of the Canal Port of Rimini began with a careful analysis with on-site inspections revealing the main deficiencies in terms of services, connections, availability of spaces, pedestrian and cycle paths. Through a questionnaire the opinions of all the stakeholders and the users gravitating around the port channel were collected. The data collected highlighted the main issues through a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats). The SWOT analysis does not give any indication of the degree of priority of one intervention over the others. For this reason, the study was deepened using indicators to measure the level of accessibility between the existing infrastructural net and the area of the Canal Port. These indicators, both quantitative and qualitative, were developed according to the model SUMI (Sustainable Urban Mobility Indicators) of the European Commission [2,3]. Once all the indicators were calculated, different planning scenarios were suggested for each of the criticalities found for the urban redevelopment of the Canal Port of Rimini. The alternative scenarios were then compared through the ANP-BOCR method (Benefits, Opportunities, Costs and Risks) to determine the degree of priority of the interventions. As numerous studies have shown, the ANP evaluation methodology is suitable to support decision-making in defining urban and territorial transformations since it can relate different aspects of the problem using both quantitative and qualitative parameters [4].

2 Expected outcomes

The project proposals for each of the criticalities identified following the SWOT analysis are as follows: 1. Creation of urban spaces of better quality, 2. Implementation of the service "Traghetto Vittoria", 3. Realization of a new exchanger parking building, 4. Improvement of cycle-pedestrian network, 5. Redevelopment and raising of docks and regularization of moorings, 6. Realization of the new Fish Market, 7.

Construction of new tourist links (Croatia), 8. Redevelopment of the slipway.

The ANP-BOCR method used to determine the degree of priority of the participations, showed that the priority actions for the requalification of the area of the Port Rimini Channel are the improvements of the cycle and pedestrian paths, the redevelopment and raising of the docks and the regularization of moorings.

After the evaluation of the projects proposed, a virtual model will be created to make a comparison between the before-after project scenarios. Using Infraworks and Twin Motion software a model will be created with the current situation of the Port of Rimini, representative of existing infrastructure (Figure 1). Then a model with the post-intervention scenario will be created. Using VR glasses, the two scenarios will be shown to users to assess their perception of the changes made as a result of the urban redevelopment of the study area [5].

Figure 1. Virtual model of the current situation of Rimini Canal Port on Twin Motion

3 Conclusions

The present report aims to elaborate a proposal for the redevelopment and the strengthening of infrastructure in the port area of the city of Rimini through a deep analysis of the critical issues and the potential of the territory. Thanks to the data from a questionnaire

addressed to stakeholders and the SWOT analysis, the eight main issues of the study area were identified. A BOCR analysis was carried out to determine the priority scale of the interventions. The restoration of cycle paths was found to be the priority action to create an area that integrates perfectly with the surrounding urban context. To compare the two pre-post intervention scenarios, a virtual model will be created to evaluate the perception of users after the cycle path changes.

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Improved Moduli Estimation of Airport Asphalt Concrete Layer Using a Machine Learning Approach Based on Heavy Weight Deflectometer Data

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Abstract

The conventional structural monitoring approach for airport runways consists in performing non-destructive tests by means of a Heavy Weight Deflectometer (HWD). The points to be investigated are usually limited to the center points of a very large mesh grid. Starting from the measured deflections at the impact points, the layers' stiffness moduli can be backcalculated. This long abstract outlines a neural computing methodology for predicting such stiffness moduli, even at unsampled locations, based on a feedforward backpropagation Artificial Neural Network (ANN) approach. Such a goal is achieved by processing HWD investigation in terms of Deflection Basin Parameters (DBPs) and backcalculation results along with other variables related to the investigation points location and the underlying stratigraphy. The neural modeling results obtained are fully satisfactory (R = 0.9864), thus suggesting that the proposed Machine Learning approach represents a reliable method to properly complete the conventional runway stiffness evaluation, based on the backcalculation procedure.

Keywords

Runway, Heavy Weight Deflectometer, Stiffness Modulus, Machine Learning, Data Augmentation

1 Methodology

The case study is a civil airport belonging to the Italian national airport network located 35 km west of Palermo, in Sicily. On the secondary runway, a HWD experimental campaign was carried out. The tests involved a portion of the runway 1800 m long and 12 m wide. The grid of interest consisted of points spaced 3 m transversely and 100 m longitudinally for a total of 5 longitudinal measurement lines and 95 total impact points. To determine pavement surface layer stiffness moduli, Road Moduli Evaluation (RO.M.E.) backcalculation technique [1] was implemented. To better understand the relationships between the stiffness modulus and its several influencing variables, a $9 - n - 1$ ANN was modelled. There were 9 neurons in the input layer, one for each type of input data: X and Y coordinates of the impact point, the homogeneous section HS, and six different Deflection Basin Parameters (DBPs) obtained by processing the results produced by the HWD investigation. The number of neurons belonging to the hidden layer was varied in the range 1 – 30 and was indicated by the n. The best hidden activation function was investigated within a group of four different functions: ELU, ReLU, TanH, and LogS [2]. Finally, a single neuron belongs to the output layer to represent the asphalt layer stiffness modulus ($\widehat{\mathrm{E}}_{\mathrm{AC}}$). Feature standardization was provided to improve model efficiency. Bayesian Regularization training algorithm was implemented, and a 5-fold cross-validation resampling procedure was introduced for a fair performance evaluation [2]. To increase ANN generalization capabilities, it was decided to nearly double the initial dataset by interpolating the backcalculated stiffness data at a midpoint between two successive impact points of the same measuring line. Such data analysis technique

is referred to as data augmentation. The function used as interpolator was the modified Akima [2].

2 Findings

Although the starting dataset is highly variable both in terms of measured deflections and backcalculated moduli, the proposed neural model returns very satisfactory results in terms of Pearson coefficient R, mean squared error MSE, and adjusted coefficient of determination R^2_{adj} (Table 1).

Inputs	Output	Act. Fun.	Best Arch.	R	MSE	R^2_{adj}
DBPs, HS, X, Y	$\widehat{E}_{AC}$	ELU	9-18-1	0.9804	0.0501	0.9303
		ReLU	9-14-1	0.9555	0.0963	0.8441
		TanH	9-26-1	0.9807	0.0439	0.9312
		LogS	9-23-1	0.9864	0.0321	0.9516

Table 1. Summary results of the proposed neural models.

- The optimal number of neurons in the hidden layer is within the range 14 – 26, depending on the specific activation function;
- All the optimized neural models have produced reliable stiffness prediction, with a maximum percentage difference, between the LogS-ANN and the ReLU-ANN, equal to 3% in terms of R values;
- The best performing ANN model is characterized by 23 neurons in the hidden layer and a logistic sigmoid activation function, with R and MSE values equal to 0.9864 and 0.0321, respectively (Figure 1).

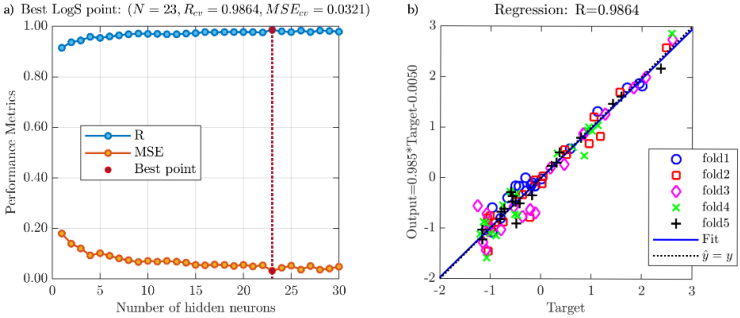

Figure 1. Performance metrics (a) and 5-fold Regression results (b) of the LogS-ANN model.

3 Conclusions

The proposed neural computing approach was able to predict the stiffness modulus at any point on the runway. It has been developed with respect to the Palermo runway, but it could be easily adapted to any runway/paved area. It would be interesting to implement additional information about deflections historical series to evaluate if the presented methodology is suitable also for predicting pavement deterioration state evolution and scheduling intervention priorities over time.

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Recharge Traveling: The Electric Road System

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Abstract

The research program aims to investigate in-transit electric charging on high-capacity roads via dynamic contactless inductive charging that is adaptable to any type of vehicle. The line of work adopted is developed in five main stages. Construction of an asphalt ring with a length of 1050 meters, fed with a power of 1 MW. Subsequently, the methodology for incorporating "Dynamic Wireless Power Transfer" technology to the different main ranges of electric vehicles (cars, buses, trucks) is evaluated. The result sought to be achieved is that of an infrastructure on top of another one. The system will be ensured with advanced 5G connectivity in order to guarantee maximum road safety and V2I communications. The next step concerns the optimization of the road pavement, in terms of the various component elements and mix design materials, in order to make it more durable and not alter the efficiency of the inductive load. Simultaneously and at the conclusion of each experimental phases, benefits and environmental impacts will be evaluated.

Keywords

DWPT, electric vehicles, mix design, inductive load

1 Methodology: The design of the test ring

The goal of the ring asphalt pavement construction is to study the interaction of the multiple variables that make up the DWPT system [1]. Once the study regarding the installations (power supply, distribution, and EMF protection) has been completed, the definition of the infrastructure in terms of the interaction of asphalt materials with EMFs is continued. The route has been divided into 7 different typological sections, characterized by different construction details and materials (Table 1). Each section refers to different road types. The purpose is to analyze the behaviour of the system in terms of efficiency on different types of road network.

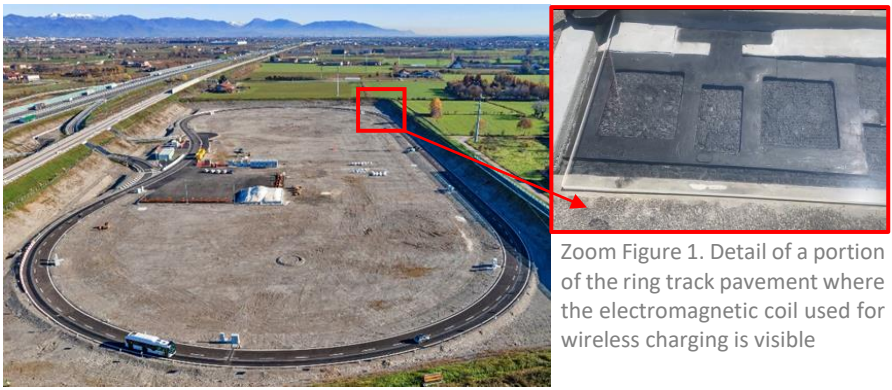
Section	Wearing Layer	Binder Layer	Upper Installation Layer
1	DP, MA	MA	IG, S
2	DP, MA	MA	S
3	DP, MA	MA	-
4	CP, MA	MA	IG, S
5	CP, MA	MA	-
6	CP, UA	UA	S
7	CP, UA	UA	-

Table 1. Typologies of transversal sections constituting the pavement of the road ring (**DP**: drainage pavement; **CP**: closed pavement; **MA**: modified asphalt; **UA**: unmodified asphalt; **IG**: induction grout; **S**: sheath)

System efficiency in terms of energy transferred from the grid to the vehicle is expected to tend toward 88%. Two representative electric vehicles are expected to run continuously during the tests: Iveco Intercity Bus and Fiat 500 utility car (Table 2 and Figure 1).

Vehicle	Speed [km/h]	Energy Consumed for 1 km [kWh]	Energy Stored for 1 km [kWh]
Bus Iveco	70/80	1.3/1.5	1.1/0.9
Fiat 500 car	70/100	0.16/0.2	0.35/0.25

Table 2. Types of vehicles circulating on the road test ring



Zoom Figure 1. Detail of a portion of the ring track pavement where the electromagnetic coil used for wireless charging is visible

Figure 1. Trial field photography with vehicles on the road: Iveco Intercity Bus and Fiat 500 utility car

The assembly of the project was composed of plant laying times and the time required for the civil construction work. Instead, the system consisting of infrastructure, plant, and working electric vehicles has been in operation since June 2022.

The bitumen used for the mixtures is a modified hard with added fibers and innovative antioxidant additives in order to be able to ensure controlled aging under the inductive load of electromagnetic fields. The effect of electromagnetic rediaction results in a deupaperation of the chemical bonds characterizing the bituminous binder[2].

Currently, data is being collected that, as far as the mechanical behavior of the various types of pavements (shown in Table 1) subjected to the electromagnetic field, will be as follows:

- sampling of pavement cores for each type of cross section and subjecting them to mechanical tests (Resilient Modulus, Indirect Traction, and Marshall Resistance)

- bitumen extracted with the aid of toluene (250 ml toluene for 300g asphalt mix) will be subjected to rheometric tests in order to derive Master Curves.

Specimen sampling will be scheduled quarterly.

2 Conclusions

Evaluations that will be carried out during the trial period will address the infrastructure and components. Developments of an electricity distribution architecture capable of integrating locally produced energy from renewable sources with energy available from the national distribution grid will be evaluated. Once the system is integrated by technology on vehicles, the need for optimization by relative homologation will become increasingly apparent. Thus, the expansion of remote monitoring and remote control systems using digital platforms and EMF assessments will have to be strengthened. Furthermore, the analysis of environmental impacts will be developed on two different orders of evaluation: evaluation of environmental benefits compared to the current fleet on traditional highway (engines running on the internal combustion principle); evaluation of environmental benefits compared to the plug-in system. In both comparisons, different emission contributions will be analyzed, both in terms of direct and indirect emissions.

References

[1] Lundberg, A. EMC test of Electreon AB WPT system in situ at Visby. RISE Research Institute of Sweden AB, 2021.

[2] Montepara, A., Giuliani, F., Merusi, F., Italia, P., and Valentinetti, M. The rheological analysis of road bitumens according to the new European guidelines: Experimental determination of equiviscosist temperatures (evt). RASSEGNA DEL BITUME, 54, 20–28, 2009.

S-VECD model to investigate the fatigue performance of asphalt mixtures

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Abstract

The simplified viscoelastic continuum damage (S-VECD) model allows to effectively determine and predict the fatigue performance of asphalt mixtures from the results of dynamic modulus tests in axial compression configuration and cyclic fatigue tests in direct tension configuration. Differently from the existing fatigue laws, the S-VECD model provides the damage characteristic curve, which is an intrinsic property of the material describing the damage evolution. A material-dependent energy-based failure criterion is also considered. Moreover, the application of the method on small specimens with 38 mm diameter allows less time-consuming laboratory tests and less cores to be extracted from the pavement. This study shows the reliability of the S-VECD model on six non-conventional asphalt mixtures in comparison with two control ones, characterized through cores extracted from full-scale field trials along Italian motorways.

Keywords

Fatigue performance; viscoelastic continuum damage (VECD), damage characteristic curve

1 Materials and methodology

Eight dense-graded mixes for binder and base layers are studied. They have the same aggregate gradation, containing 25÷30% of RAP by aggregate weight, with NMAS of 20 mm. The bitumen content is 4.6% and 4.2 % by aggregate weight for binder and base layer, respectively. The mixes differ for the binder composition and production process:

- H (reference): SBS modified, produced at 170 °C;
- GC: 50/70 plus plastomeric compound with graphene added via dry method, produced at 170 °C;
- PC: 50/70 plus plastomeric compound added via dry method, produced at 170 °C;
- W: SBS modified plus WMA chemical additive, produced at 140 °C.

The mixes are investigated applying the S-VECD model on specimens with 38 mm diameter and 110 mm height, horizontally cored from two full-scale field trials. First, dynamic modulus tests are performed at various frequencies and temperatures maintaining an average strain level of 63 με. The 2S2P1D model is used to fit the experimental storage modulus data [1]. Then, fatigue tests are performed at the frequency of 10 Hz at 21 °C [2]. The S-VECD model provides the damage characteristic curve, an intrinsic property of the material that shows how the material integrity (pseudo stiffness, C) decreases as the amount of damage (S) increases. The energy-based failure criterion D^R is adopted. D^R represents the rate of change of the averaged released pseudo strain energy during the fatigue test. Higher D^R values mean greater material toughness. Finally, the synthetic index S_{app} is calculated, taking into account the stiffness and fatigue properties. S_{app} varies from 0 and 50, and higher values indicate better fatigue performance.

2 Findings

Figure 1 reports the storage modulus mastercurves with the average air void content of the tested specimens, and the *C*-*S* curves with the D^R values.

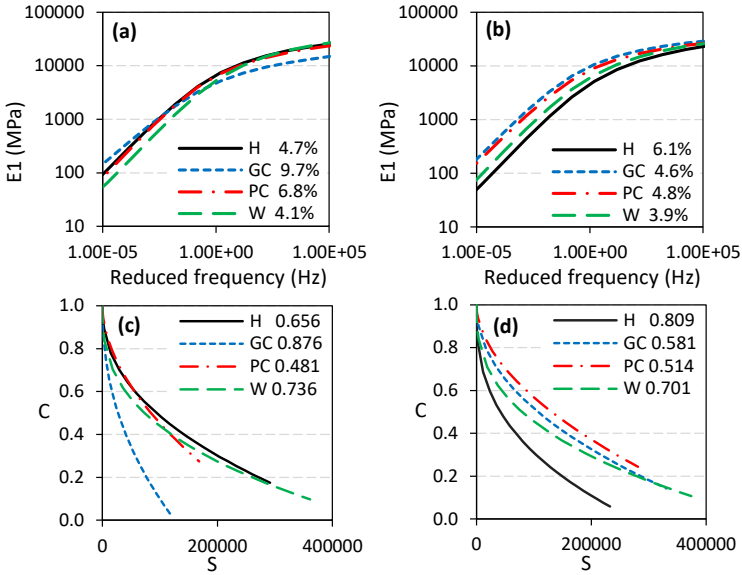

Figure 1. Storage modulus mastercurves at 21.1 °C with average air void content values and damage characteristic curves with D^R values: (a)-(c) binder mixtures, (b)-(d) base mixtures.

Regarding the binder layer, the stiffness of PC is comparable to H despite the higher void content due to the plastomeric compound. The latter stiffens the mix and leads to brittle behaviour, as demonstrated by the higher *C* and lower *S* values at failure and low D^R value, which denote less damage tolerance and toughness. The *C*-*S* curve and D^R value of GC are deemed unreliable, because the high air void content (i.e. 9.7%) makes the small geometry non-representative. W shows the highest D^R value, indicating high toughness, and the longest *C*-*S* curve, indicating a postponed failure. This is likely due to the lower RAP oxidation thanks

to the lower production temperature. All the observations well reflect on S_{app} values reported in Table 1.

Regarding the base layer, PC and GC have comparable stiffness, followed by W and H, mainly due to the volumetric properties. As can be observed, a higher stiffness leads to an upward position of the *C-S* curve. In addition, GC and PC have similar fatigue behaviour, worse than H because of the higher *C* at failure and lower D^R values, indicating a low ability to withstand damage likely due to the unmodified bitumen. W and H reach similar pseudo stiffness at failure, but W is capable to accumulate a higher amount of damage (*S*), as expressed by its higher S_{app} value (Table 1).

Layer	Binder				Base			
Mix	H	GC	PC	W	H	GC	PC	W
S_{app}	18	12.7	13.9	29	22	12.0	15.2	28

Table 1. *Sapp* values of the investigated mixes.

3 Conclusions

The S-VECD model is a reliable method to investigate also non-conventional mixtures. Further research should be conducted on the analysis of open-graded mixtures. The experimental results can be directly used as input for FlexPAVE™ pavement performance simulations under moving loads and actual climatic conditions.

References

[1] AASHTO TP 132:2019. Standard Method of Test for Determining the Dynamic Modulus for Asphalt Mixtures Using Small Specimens in the Asphalt Mixture Performance Tester (AMPT)

[2] AASHTO TP 133:2021. Standard Method of Test for Determining the Damage Characteristic Curve and Failure Criterion Using Small Specimens in the Asphalt Mixture Performance Tester (AMPT) Cyclic Fatigue Test

Sustainable Pavements and Road Materials

(F. Russo, S.A. Biancardo, R. Veropalumbo, F. Abbondati)

Proceedings of the
7th SIIV Arena

The SIIV Arena is a space for discussion in which PhD students and young scholars from various universities illustrate their research on topics of specific interest for the Scientific Disciplinary Sector ICAR/04 "Roads, Railways and Airports".
This volume collects the proceedings of the 7th SIIV Arena, held in Naples on 9 September 2022, and held as part of the XVIII International SIIV Summer School: "Sustainable Pavements and Road Materials". The use of construction and maintenance technologies based on principles of sustainability, resilience and circular economy, are a reference, in synergy with the use of secondary raw materials, for achieving adequate mechanical performance for the road structure, with a reduced environmental impact. and costs. The growth gradient recorded in the field of civil infrastructures has defined an incessant use of natural resources with consequent negative effects in terms of environmental sustainability. The reuse of waste in mix design processes and the use of in situ processing systems and/or "low energy" technologies (i.e., cold and/or warm asphalt mixtures) fully meet the objectives underlying the principles of the circular economy.
This volume aims to collect the most innovative research in the sector presented in the context of the 7th SIIV Arena by analyzing aspects relating to the design, construction and maintenance of the pavement and road infrastructure as a whole.

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