sustainability

Editorial

Sustainable Pavement Engineering and Road Materials

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Citation: Bocci, E. Sustainable Pavement Engineering and Road Materials. *Sustainability* **2022**, *14*, 2166. https://doi.org/10.3390/su14042166

Received: 1 February 2022
Accepted: 10 February 2022
Published: 14 February 2022

Contents of the Special Issue

One of the most topical research areas currently concerns the identification and improvement of technologies against climate change, environmental pollution, exploitation of natural resources, and the economic crisis. Of course, the field of road pavement engineering has also been involved in this battle. In recent years, themes of sustainability and circular economy have become the main keywords for scientists, administrations, designers, and constructors worldwide. This is also testified by the 13 contributions published in this Special Issue, authored by European, Asian, African, and South American research teams.

In the field of pavement engineering, the word "sustainability" can be related to several aspects, including road materials and their performance, the management of temperatures and emissions during road construction and service life, and analyses of the socio-economic and environmental impacts generated by the road infrastructures.

Concerning the theme of road materials, five papers of this Special Issue (contributions 1, 7, 10, 11, and 12) deal with the use of wastes or by-products in different types of mixtures. In particular, contributions 1 and 6 regard porous cement concrete (or pervious concrete), a kind of sustainable urban drainage system that allows us to face the problems of storm water management, urban heat island, and air pollution. The paper by Elizondo-Martinez, Tataranni, Rodriguez-Hernandez, and Castro-Fresno (contribution 1, feature paper) investigates the possibility of substituting proportions of cement with metakaolin or geopolymer pastes, whose production is less harmful to the environment. The results showed that the replacement of 5% cement with metakaolin can increase both permeability and indirect tensile strength. In contrast, the geopolymer mixtures proved to require an accurate proportion of the mix components in order to balance the permeability and the mechanical properties. However, the findings are promising and demonstrated that these materials can be a suitable alternative to traditional porous cement concrete. The paper by Hung, Seo, Kim, and Lee (contribution 7) focuses on the influence of blended aggregate and blocking materials on the mechanical and permeability characteristics of porous cement concrete. The study provided the optimum proportions between coarse, intermediate, and fine aggregates in terms of strength and permeability. In particular, the results showed that porosity and permeability decrease when increasing the content of fines. Moreover, the research proved the efficacy of vacuum-cleaning and high-pressure spraying in partly restoring the porous concrete permeability when the voids become clogged. Vaitkus, Gražulytė, Kravcovas, and Mickevič (contribution 10) evaluated the role of foamed bitumen-treated base courses to the bearing capacity of the pavement structure using a falling weight deflectometer. The study showed that the foamed bitumen-treated layer has a mechanical behavior that evolves with time due to material curing. For this reason, the mechanistic–empirical pavement design approach has to be updated in order to account for these kinds of mixtures and their peculiar characteristics. Moreover, the effect of the water content in the layer should also be incorporated in the correction factors. Contributions 10 and 11 are review articles. The paper by Bocci and Prosperi (contribution 11) aims at describing the chemical phenomena that happen during bitumen aging, specifically, loss of volatiles, oxidation, and physical and steric hardening. To restore the aged bitumen properties, rejuvenators should rebalance the colloidal components, disrupt the asphaltene clusters, and re-establish the proper molecular mobility. The literature review allowed us to emphasize the importance of using different laboratory approaches for a precise and clear overview of how bitumen ages and rejuvenates in order to encourage more and more recycling of reclaimed asphalt pavement (RAP). The review by Mohammed, Koting, Katman, Babalghaith, Abdul Patah, Ibrahim, and Karim (contribution 12) describes the possible solutions to reuse coal bottom ash (CBA), a kind of hydraulic material from coal production. In particular, one of the most promising fields where CBA can be recycled is pavement construction, as it can be an aggregate replacement, cement replacement, additive in bitumen, and filler in hot-mix asphalt (HMA). All these solutions showed excellent outcomes, but in-depth preliminary analyses are required to characterize CBA, which is highly heterogeneous by nature, and CBA-containing mixtures.

Sustainability in road engineering can also be achieved by increasing the performance of the materials against traffic loads and environmental factors, thus extending the durability of the whole pavement system. From this perspective, the paper by Ragni, Canestrari, Allou, Petit, and Millien (contribution 2) investigated the shear resistance at the interface between old and new HMA layers in presence of geogrid reinforcement. The use of geogrids represents an extremely effective and sustainable solution for pavement maintenance, as it allows us to avoid the reconstruction of the entire thickness of the HMA layers and to increase the durability of the overlays, typically subjected to early reflective cracking. The research aimed at analyzing the performance of geogrid-reinforced interfaces against static and cyclic shear stresses. To this scope, three types of double-layer cores, i.e., unreinforced, reinforced with a carbon fiber geogrid, and reinforced with a glass fiber geogrid, were taken from a full-scale trial section and tested in the laboratory. The study showed different performances of the interfaces according to the reinforcement type and specimen temperature. However, the resistance against debonding of the reinforced interfaces was comparable to that of the unreinforced specimens, encouraging the adoption of this maintenance solution. The review by Fusco, Moretti, Fiore, and D'Andrea (contribution 4) presents the most commonly used nano-additives for HMA mixtures: nanoclays (NC), nanosilicates, carbon nanotubes (CNTs), graphene nanoplatelets (GNPs), nano-calcium oxide (CaO), and nano-titanium dioxide (TiO_2). The literature review highlighted that the performance of these mixtures strongly depends on type, concentration, and dispersal of the used nano-additive. Such variables influence the bonding properties, the viscosity, the resistance to aging, and the self-healing, consequently improving the rutting and fatigue behavior. Mokoena, Mturi, Maritz, Mateyisi, and Klein (contribution 13) studied the critical factors for the development of the temperature maps of Africa for the selection of the most suitable performance-graded bitumen in pavement design and construction. This choice is fundamental in providing an adequate duration of the HMA service life. In particular, the paper encourages the selection of a proper pavement temperature model for each climatic zone of a country, the evaluation of the urban heat island phenomenon in the bitumen choice, and the use of downscaled global climate models and pavement temperature maps.

For the sustainability of the road pavement, temperature is a key factor not only during the service life of the infrastructure but also when the HMA is produced. In fact, an incorrect management of the virgin aggregate, RAP, and bitumen temperatures at the mixing plant can determine excessive pollutant emissions and improper performance of the HMA. Calabi-Floody, Valdés-Vidal, Sanchez-Alonso, and Mardones-Parra (contribution 3) evaluated the gas emissions, the energy consumption, and the production costs of HMA manufactured at different temperatures, including different RAP contents (up to 30%). In particular, natural zeolite was used in the warm mix asphalt (WMA) and allowed us to reduce the mixing temperature from 155 °C to 125 °C. The laboratory results and analyses showed that the CO_2 emissions reduced by 23% and 37% for the WMA, respectively, without and with RAP, while the lower benefits were obtained in terms of CO emissions. The energy consumption decreased by 5–13%, but this did not allow total compensation of the cost of the zeolite. Bocci, Prosperi, Mair, and Bocci (contribution 5) investigated how keeping the HMA at high temperature for a long time influences the mix properties. The research demonstrated that HMA handling in the laboratory, during quality assurance and quality controls, is extremely important, since keeping the material in the oven for a prolonged time or re-heating it may significantly affect the test results. In contrast, in full-scale road construction, cooling and temperature segregation represent a higher risk for HMA than aging, but these can be limited using insulated trucks.

The sustainability of road infrastructure is also associated with pavement–tire interfaces, in particular, to the rolling resistance of vehicle tires, which is strictly related to fuel consumption. Guo, Li, Ran Zhou, and Yan (contribution 6) modelled the tire–pavement contact surface, with specific reference to trucks and buses, to predict stresses and rolling resistance under different rolling conditions. The proposed exponential equation describes a method that can forecast the rolling resistance related to the working conditions of truck–bus tires, allowing the estimation of fuel consumption and greenhouse gas emissions.

When administrations and designers have to plan construction or maintenance work, an accurate prediction of the environmental, economic, and social impact is fundamental in the optic of sustainability. Two papers of this Special Issue deal with this topic. Halámek, Matuszková, and Radimský (contribution 8) carried out an ex-post cost and benefit (CB) analysis on a set of 144 regional road modernization projects in Czech Republic. In particular, they compared the results of the ex-post CB analysis with those of ex-ante CB analysis in order to identify the best indicators for supporting administrations in defining where and how much to invest. The study showed that the money spent for regional road modernization was 11% lower than expected. The impact of the projects on traffic accidents was not as positive as foreseen in the ex-ante CB analysis, negatively influencing the net present value and the weighted profitability index. Therefore, the authors recommend eliminating the impact on traffic accidents in the ex-ante analysis. Balaguera, Alberti, Carvajal, and Fullana-i-Palmer (contribution 9) performed a life cycle analysis (LCA) to identify the recycled soil stabilizer with the lowest environmental impact for two rural roads in Colombia. In particular, they considered brick dust, fly ash, sulphonated oil, and recycled polymeric emulsion. The sulphonated oil was not suitable, as it required significant additional resources to become a stabilizer. Moreover, the manufacture of the polymer and its application as a stabilizer were also found to have great impacts. Brick dust and fly ash showed the highest impact in the stabilizer manufacture step but resulted the best solutions for the two investigated rural roads in terms of global warming potential.

All the valuable and interesting papers included in this Special Issue significantly contribute to the knowledge of road material behavior and the new frontiers of pavement engineering. Many solutions can be found, investigated, and validated in order to make the road infrastructure industry sustainable. The hope is that these innovations can soon become the normality.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The author declares no conflict of interest.

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