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Innovative light-coloured porous asphalt for low-impact pavements: A laboratory investigation

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ABSTRACT

In recent years, research is pushing toward more sustainable solutions in the road sector such as cool pavement and eco-friendly paving components. Cool pavements are advanced pavement technologies characterized by lower surface temperature thanks to the use of light-coloured binders and an open-graded structure. In this framework, the present study intends to provide a laboratory characterization of two different open-graded wearing courses produced with Construction and Demolition waste (CDW) aggregates and virgin aggregates and with a transparent resin-based binder. The final aim of the research is to provide scientific evidence on the possible application of the adopted resin-based transparent binder with light-coloured aggregates for open-graded wearing courses in order to minimize the Urban Heat Island phenomenon. The results show that the addition of 50% of CDW aggregates to the porous asphalt enhances the abrasion resistance and the mechanical performance of the mixture.

1. Introduction

Nowadays, the world’s population living in cities has exceeded the 50 %. This proportion is expected to increase to two third by 2050 [1]. Rapid urbanization and population growth continuously change the landscape and land use. More densely populated cities result in the development of new roads, buildings, and infrastructures that replace vegetation and urban green spaces. Such growth leads to more impermeable dark-coloured surfaces which give rise to less infiltration, drainage, and heat dissipation [2,3]. Furthermore, the always-increasing aesthetic demand of people has transformed the traditional black-coloured pavement into a monotonous design solution unable to satisfy the needs of modern cities. For this reason, coloured pavements started to become popular for embellishing residential areas, routes, parks, and historical city centres and to differentiate pedestrian and bicycle-dedicated lanes [4]. Different studies highlighted that coloured pavements are more appreciated by users [5,6]. They meet the aesthetic standard of people and are more in harmony with the natural landscape [7]. Because of their colour, light-coloured pavements are perceived by users as more pleasant than the traditional bituminous ones, since white and light objects are associated with positive feelings [5]. Given that traditional pavements are black asphalt, the use of colour can be a proper way to kindly integrate the always-increasing urbanization into the environment and lower their visual impact. It is demonstrated how much it is important to create infrastructures that are pleasant for people and that can properly match the surrounding landscape [8]. The most common way for creating coloured and cool pavements is using light-coloured asphalt, made with a bitumen-based clear binder, or with the use of coloured pigments [9,10]. Widely used are even coloured asphalt mixtures made with transparent resin. Synthetic resin binders are particular materials made with polymers, resins and oils. Different studies demonstrated how the use of synthetic binders enhances the mechanical properties with respect to traditional bitumen [4,11,12]. Furthermore, synthetic binders can be easily coloured and in practice, they can reduce the visual and environmental impact of black bitumen. Therefore, is it possible to use specific aggregates to create wearing courses that have the same colour as the surrounding landscape [13]. With these innovative binders it is possible to develop light pavement in the historic city centres without a negative impact on the environment but by enhancing its beauty instead [14]. To further emphasize the benefits of light-coloured pavement, it is worth mentioning the Urban Heat Island (UHI) phenomenon. The UHI is the phenomenon by which the urban area experiences an increment in temperature compared to the rural one [15]. Currently, the countryside has an annual mean daily

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temperature of 1 to 3 °C lower than its urban counterpart [16]. The effects directly connected to the UHI are a reduction in the quality of the urban environment, the worsening of thermal discomfort, and the rise of health problems. For instance, Kousis et al, demonstrated that the use of an innovative polyolefin-based synthetic transparent binder significantly implements the UHI mitigation potential of the pavement [17]. Moreover, the grading distribution and the mix design of pavements play a key role in the mitigation of the UHI effect. In such a context, the use of pervious pavements, and in specific porous asphalt concretes, is a proper solution to face the aforementioned phenomenon [18].They are mostly used for stormwater management but it is demonstrated that they even have evaporative cooling effects [19]. In fact, when water is in the pores of the pavement, evaporative cooling reduces the air temperature and consequently mitigates the urban heat island [20]. The high percentage of interconnected voids and its capacity to infiltrate water, reduce the UHI phenomenon, making the porous asphalt a suitable application for urban pavement [21]. In addition, to keep up with the present environmental need, a crucial aspect in the design of innovative pavements is the use of waste material. Aggregates represent 90–95 % of asphalt mixtures by weight. They are the principal component of pavement layers, resulting in the consumption of millions of tons of virgin aggregates each year [9]. The consequent detrimental effect on the environment can be reduced by introducing the use of recycled materials in the design of new pavement or for the maintenance of old ones. In particular, construction and demolition waste (CDW) aggregates are suitable materials that can be used in the context of UHI mitigation [22]. The construction and demolition waste can contain concrete, bricks, plaster, and other types of materials such as wood and plastic [23]. When CDW materials are mainly composed of concrete and pozzolanic materials, they provide a light greyish colour to the layers, making them appropriate for cool pavement [24]. Therefore, before using it, this type of material needs to undertake specific treatments. In Italy, in 2018 around 41 million tons of construction and demolition waste were generated and discharged [25]. Nowadays, construction and demolition materials are a great alternative to natural aggregates and they are widely used in different layers of road pavement [26]. This possible recycling method could drastically reduce the quantity of waste material produced in one year [27]. The present research takes place from a perspective of circular economy, sustainable development, and integration of the new infrastructure with the surrounding landscape. The aim of this work is to evaluate the characteristics of an innovative porous asphalt made with 50 % of recycled concrete aggregates from CDW and a polyolefin-based synthetic transparent binder. The latter is a proper alternative for light-coloured asphalt, and it is able to not lose transparent properties during its lifetime. The innovative material is compared with a traditional porous asphalt made with virgin aggregates and bitumen and with a porous asphalt made with the same transparent binder but with only virgin aggregates. The physical, mechanical and functional properties of the mixture are evaluated through a complete and fulfilling laboratory investigation.

2. Materials and test methods

In the present research, the mechanical, physical, and surface properties of three different mixtures for porous wearing course, composed of virgin and recycled aggregates, bitumen, and synthetic transparent binder have been evaluated. The objective of the study was to compare the three different mixtures and verify if the combined use of transparent binder and CDW aggregates is suitable for open-graded layers for UHI mitigation.

2.1. *Material*

2.1.1. *Aggregates*

For this study, an accurate selection of the type, colour, and size of aggregates was required. The white colour of the virgin aggregates was a crucial characteristic since the synthetic binder is transparent and emphasizes their colour. Two types of materials are used for the analysis:

- Virgin aggregates: light-coloured limestone aggregates, mainly composed of calcium carbonate, coming from the province of Ancona, Italy (Fig. 1a).
- Recycled concrete aggregates: coming from the treatment and selection of construction and demolition waste from the province of Bologna, Italy (Fig. 1b).

In Table 1 are reported the volumetric and mechanical properties of the recycled concrete aggregates, hereafter named CDW aggregates, while the properties of the virgin aggregates are presented in Table 2.

A loss of 20.3 % for LA of CDW aggregates was measured, which is in

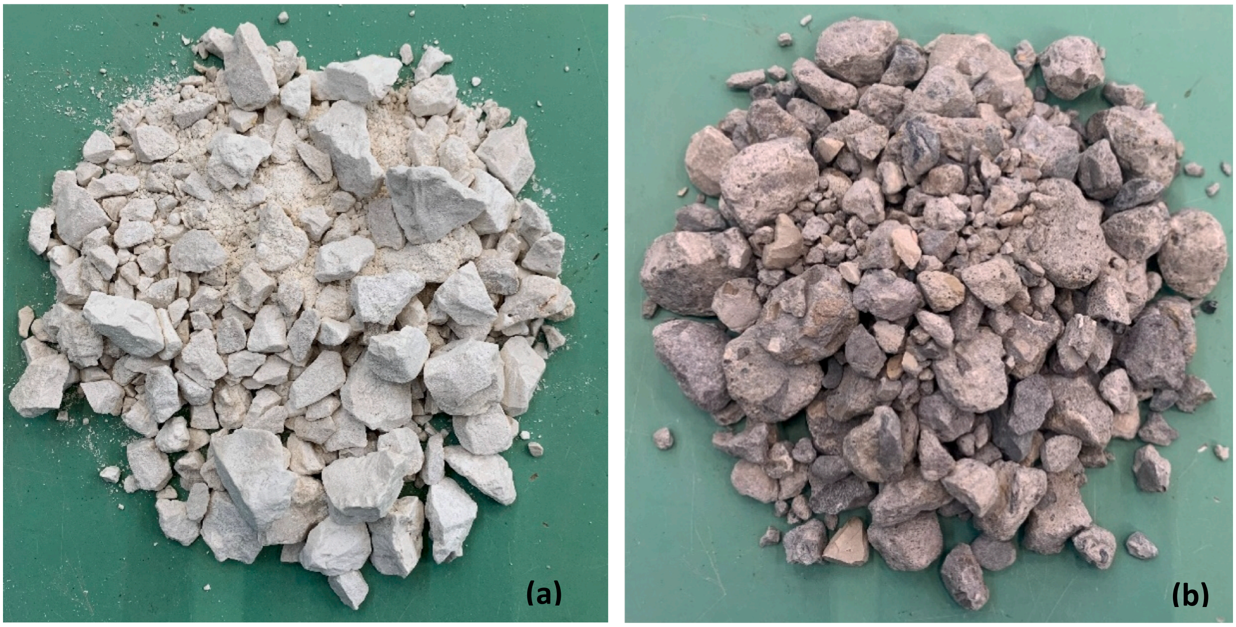

Fig. 1. (a) Virgin limestone aggregates and (b) CDW aggregates.

Table 1
Volumetric and mechanical properties of CDW aggregates.

Properties	Unit	Standard	CDW
Apparent aggregates density	g/cm^3	EN 1097–6	2.563
Resistance to fragmentation (LA)	%	EN 1097–2	20.3
Water absorption (WM$_A$)	%	EN 1097–6	4.67
Flakiness index	%	EN 933–3	2
Shape index	%	EN 933–4	4.7
Rc*	%	EN 933–11	88.9
Ru*	%	EN 933–11	9.2
Rb*	%	EN 933–11	1.2
Ra*	%	EN 933–11	0.6
Rg*	%	EN 933–11	0.0
X*	%	EN 933–11	0.0

* These are the constituent materials of the CDW aggregates: Rc = concrete, concrete products, mortar, concrete masonry units; Ru = unbound aggregate, natural stone, hydraulically bound aggregate; Rb = clay masonry units, calcium silicate masonry units, aerated non-floating concrete; Ra = bituminous materials; Rg = glass; X = other.

Table 2
Physical and mechanical properties of virgin limestone aggregates.

Properties	Unit	Standard	Limestone
Apparent aggregates density	g/cm^3	EN 1097–6	2.674
Resistance to fragmentation (LA)	%	EN 1097–2	21.5
Resistance to polishing	PSV	EN 1097–8	42
Flakiness index	%	EN 933–3	6
Shape index	%	EN 933–4	2.2

line with the LA value for natural aggregates generally required for surface layers and lower than the value traditionally linked to recycled aggregates, reported in different studies [25,28]. Looking at the constituent materials, it is clear that the main component of the CDW aggregates is Rc, corresponding to cement concrete. All the other volumetric and mechanical properties investigated are comparable with those found in various research [27,29]. As for the limestone aggregates, the values shown in Table 2 are in line with the requirements for aggregates for surface layers.

2.1.2. Binder

The commercially available binder used in this study is an innovative transparent binder, manufactured by mixing polymers, resins, and oils. It is a polyolefin-based synthetic transparent binder, which is produced in chips form, that melts when it gets in contact with the hot aggregates in the drum mixer of a traditional asphalt production plant. Thanks to this property, the polyolefin-based binder does not need to be pre-heated before being added to the mix. Fig. 2 shows the shape of the chips at room temperature. For what concern the bituminous binder for the reference mixture, is a polymer-modified bitumen (PmB 45/80–70), specific for porous asphalt.

Table 3 reports the mechanical properties of the binder. Due to confidential reasons, the chemical characteristics and the exact percentage of the constituents of the binder cannot be provided. It is worth mentioning that the test on the synthetic binder was developed following the European standard EN 12697–11, specific for bituminous binders, despite the adopted synthetic binder is completely bitumen free. As a consequence, from the results it is evident the differences between the synthetic binder and a traditional bitumen.

Fig. 2. Polyolefin-based synthetic transparent binder.

Table 3
Characteristic of the polyolefin-based synthetic transparent binder.

Properties	Unit	Standard	Value
Specific weight	g/cm^3	EN ISO 3838	0.850
Viscosity at 160 °C	Pa·s	EN 13702	> 0.7
Penetration at 25 °C	0.1 mm	EN 1426	55
Softening point	°C	EN 1427	> 75
Ductility	cm	EN 13398	5
Elastic recovery	%	EN 13590	n.m.

2.2. Test method

The experimental program was set up to evaluate the mechanical, physical, and functional proprieties of the mixtures to investigate the possible use of the polyolefin-based synthetic transparent binder and CDW aggregates for the production of low-impact porous pavements. The optimal dosage of bitumen and of the polyolefin-based synthetic transparent binder has been previously investigated in preliminary laboratory studies. Three different draining mixtures were produced. The materials and label of each mixture are listed below:

- Mix1, for the mixture composed of the virgin aggregates and the polyolefin-based synthetic transparent binder;
- Mix2, for the mixture composed of CDW aggregates and the polyolefin-based synthetic transparent binder;
- Mix3, for the conventional draining mixture, composed of virgin aggregates and bitumen.

For each mixture, the same tests were performed to compare the performances of the CDW aggregates and the innovative binder. The experimental program encompassed the following laboratory tests:

- Granulometric distribution of virgin and recycled aggregates (EN 933–1);
- Preparation of samples using Shear Gyratory compactor (EN 12697–31);
- Air voids content (EN 12697–8);
- Indirect tensile strength at 25 °C (EN 12697–23);
- Indirect tensile strength ratio (EN 12697–12);
- Indirect tensile stiffness modulus at 10 °C, 20 °C, and 30 °C (EN 12697–26);
- Particle loss of porous asphalt (EN 12697–17);

- Hamburg Wheel-Track testing of Compacted Hot Mix Asphalt (AASHTO T 324);
- Vertical permeability (EN 12697–19);
- Skid resistance (EN 13036–4).

The optical and thermal properties of the mixture obtained with the polyolefin-based synthetic transparent binder were not further investigated since they have already been measured in previous studies that evaluated the low impact of the proposed mixture in terms of UHI phenomenon [14,17]. The aforementioned tests were developed with the same binder and aggregates.

3. Results and discussion

3.1. Size distribution

To determine the size particle distribution of the virgin and recycled aggregates a sieve analysis was performed in compliance with the European standard EN 933–1. The grading distribution was designed considering some Italian technical specifications for porous asphalt. The aim was to maximize the use of CDW aggregates respecting the design gradation curve. After the characterization, it was possible to design the Mix2 using 50 % of CDW aggregates. The percentages of each aggregate adopted for the different mixtures are reported in Table 4.

The gradation curves of the three different mixtures are reported in Fig. 3.

The use of recycled concrete aggregates did not change the gradation curve. In fact, it was possible to obtain almost the same curve using the 50 % of CDW.

3.2. Samples preparation

The mixtures were prepared using a laboratory mixer based on a standardized procedure. The aggregates were preheated at 180 °C for at least 4 h. The aggregates and the bitumen (5.4 % by aggregates weight) were mixed with limestone filler and cellulose fibres (0.3 % by aggregates weight) as a stabilizing agent. A total of 11 samples were compacted with a gyratory compactor following the EN 12697–31 standard (50 gyrations) for each mixture. For the mixtures made with the polyolefin-based synthetic transparent binder, the compaction procedure adopted was the same. The optimum binder content was defined in a preliminary laboratory investigation, based on the volumetric (air voids content, workability) and mechanical (ITS) properties of three different mixtures produced with different dosages of the synthetic binder.

During the mixing process, the binder was not pre-heated and melted before being added to the mix of hot aggregates. Fig. 4 shows the mixtures after compaction for the three different materials.

Table 4
Percentage of each aggregate for Mix1, Mix2, and Mix3.

Aggregates	Unit	Mix1	Mix2	Mix3
CDW aggregates	%	0	50	0
Limestone gravel (12/16)	%	33	20	33
Limestone gravel (8/12)	%	55	15	55
Limestone gravel (4/8)	%	7	10	7
Filler	%	5	5	5

3.3. Air voids content

The air voids content (V_a) of the bituminous specimen represents the volume of the air voids, concerning the total volume of the specimen. According to the EN 12697–8 standard, the V_a is calculated as the ratio of the maximum density of the mixture, evaluated in compliance with EN 12697–5, to the bulk density of the specimen by dimension (EN 12697–6). The value of the maximum density, the bulk density, and the air voids content are presented in Table 5.

The designed open-graded gradations allow the achievement of high porosity in the final material. The EN 13108–7 standard, which defines the requirements for porous asphalt mixtures, considers an air voids content between 12 % and 32 %. It follows that the air voids of the samples compacted at the design gyrations fit the range classification suggested by the European standard. The high percentage of air voids detected in Mix2 is connected to the presence and shape of 50 % of CDW aggregates, which usually tend to absorb the binder.

3.4. Indirect tensile strength results

The purpose of this test was to evaluate the indirect tensile strength (ITS). It is the maximum tensile stress calculated based on the peak load applied to a specimen that is diametrically loaded until it breaks. This test gives an idea of the cohesion of the mixture and the static mechanical properties. Three specimens for each mixture were tested after conditioning for at least 4 h at 25 °C following the EN 12697–23 standard. The average ITS values are reported in Table 6.

The ITS value of the mixture containing 50 % of recycled materials is higher than mixtures made with virgin aggregates. This demonstrates that the presence of CDW aggregates may result in higher ITS values due to the roughness of the surface of the aggregates, which increases the internal friction of the mixture [30]. Furthermore, it is evident how the polyolefin-based synthetic transparent binder confers to the mixture

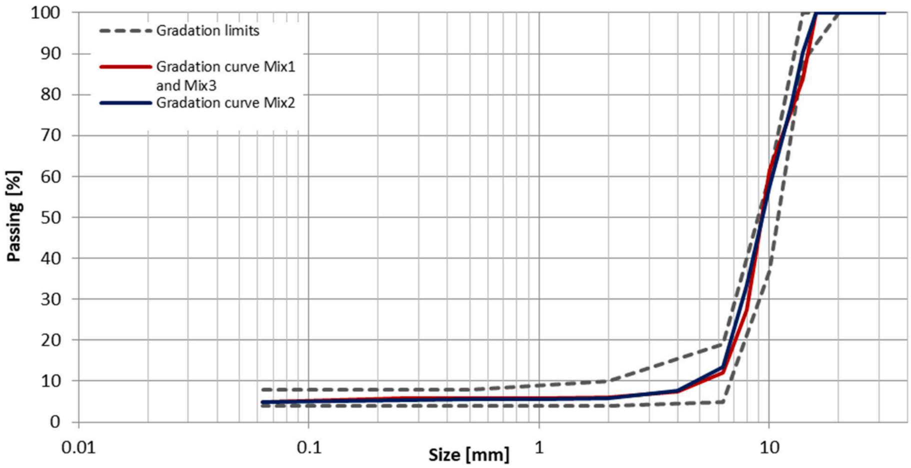

Fig. 3. Gradation limits for Mix1, Mix2 and Mix3.

Fig. 4. Specimen after compaction from Mix1 (a), Mix2 (b), and Mix3 (c).

Table 5
Volumetric properties of the mixtures.

Mechanical values	Unit	Mix1	Mix2	Mix3
Bulk density	g/cm^3	1.885	1.775	1.850
Maximum density	g/cm^3	2.353	2.371	2.244
avg. V_a content	%	18.9 (±0.87)	25.2 (±1.03)	17.6 (±0.51)

Table 6
Average results of the ITS for each mixture.

Mechanical values	Unit	Mix1	Mix2	Mix3
Max load	daN	600	696	412
Displacement	mm	1.83	2.51	2.02
Indirect tensile strength	MPa	0.45 (±0.04)	0.52 (±0.04)	0.30 (±0.001)

higher mechanical performance compared to the conventional porous asphalt mixture made with bitumen.

3.5. Indirect tensile strength ratio

The water susceptibility of the mixture was evaluated in terms of ITSR. Thus, the ITS test has been performed on specimens being conditioned in water. Three samples for each mixture were soaked in a water bath at 40 °C for 72 h and then conditioned at 25 °C for at least 4 h. The Indirect Tensile Strength Ratio (ITSR) has been calculated as a ratio of ITS in wet and dry conditions. The detailed procedure and calculation are reported in the reference standard EN 12697–12. The average results of the ITS_{dry}, ITS_{wet} and ITSR are reported in Table 7.

In this case, the presence of 50 % RA within the mixture negatively affects its moisture susceptibility. This result might also be related to the higher presence of air voids in Mix2. As for Mix1, despite a higher reduction in ITS values after the conditioning in water if compared to the bituminous mixture, still shows the best cohesion properties. It is worth noting that the lower limit for ITSR in the Italian technical specification is 75 %.

Table 7
Average results of the ITS_{dry}, ITS_{wet}, and ITSR for each mixture.

Mechanical values	Unit	Mix1	Mix2	Mix3
ITS_{dry}	MPa	0.45 (±0.04)	0.52 (±0.04)	0.30 (±0.001)
ITS_{wet}	MPa	0.38 (±0.006)	0.33 (±0.02)	0.31 (±0.02)
ITSR	%	84	63	102

Table 8
ITSM values for Mix1, Mix2, and Mix3.

Mechanical values	Unit	Mix1	Mix2	Mix3
ITSM @ 10 °C	MPa	3436 (±312)	3233 (±234)	2985 (±150)
ITSM @ 20 °C	MPa	2341 (±204)	2225 (±130)	1807 (±30)
ITSM @ 30 °C	MPa	1348 (±8)	1359 (±71)	924 (±48)

3.6. Indirect tensile stiffness modulus

The ITSM test was performed to evaluate the stiffness of the wearing mixtures and thus their dynamic-mechanical behaviour. Three different temperatures were investigated (10 °C, 20 °C and 30 °C) following the EN 12697–26 standard. In Table 8 are reported the value of the stiffness modulus at the three different test temperatures.

Comparing the mixture made with the polyolefin-based synthetic transparent binder and with the bitumen it is correct to state that the behaviours, in terms of stiffness response, are similar. The thermal susceptibility can be evaluated with the ITSM versus temperature curve described by the following equation:

$$logS = -\alpha \bullet T + \beta$$

S represent the indirect tensile stiffness modulus at the testing temperature, then α and β are experimental parameters referring to the properties of materials. Precisely, α can represent the temperature susceptibility and a higher α parameter implies that the material is more susceptible to temperature changes. The ITSM versus temperature curves and corresponding equations are reported in Fig. 5. Mix1 appears to be stiffer. For what concerns Mix2, with 50 % of CDW aggregates, it is possible to see a slight decrease in the stiffness value with respect to Mix1. When focusing on Mix3, it is clear that is the less performing. Considering the ITSM values at different temperatures, the mixtures composed of the polyolefin binder have a slightly flatter trend if compared to the bituminous mixture. This suggests that Mix1 and Mix2 are less thermo-sensitive than Mix3.

3.7. Particle loss

The scope of this test was to determine the particle loss (PL) of porous asphalt mixtures according to the European standard EN 12697–17. It was assessed by the loss of mass of samples after being turned into the Los Angeles machine. This test characterized the mixtures in terms of abrasion resistance. The average PL results are reported in Table 9 and demonstrate a higher resistance of the mixtures made with a polyolefin-based synthetic transparent binder with respect to the conventional one.

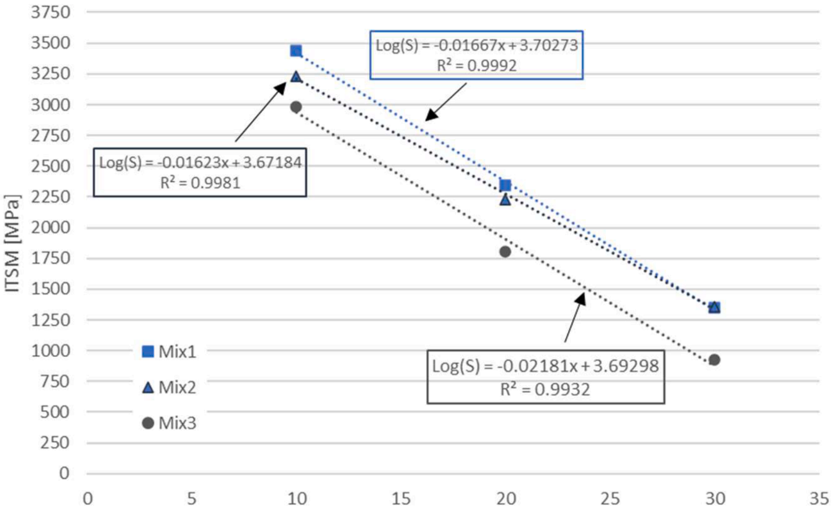

Fig. 5. ITSM measurements for each mixture at 10 °C, 20 °C, and 30 °C.

Table 9
Average particle loss of Mix1, Mix2 and Mix3.

Mechanical values	Unit	Mix1	Mix2	Mix3
Particle loss	[%]	6.7 (±0.82)	5.7 (±0.89)	21.3 (±3.65)

This test suggests that Mix3 has less cohesion than Mix1 and Mix2. This result is also in line with the higher cohesion of the experimental mixtures measured during the ITS test.

3.8. *Hamburg wheel track test results*

The test measured the rutting and moisture susceptibility of a bituminous specimen in accordance with the AASHTO T 324–11 standard. The specimens were submerged in a temperature-control water bath of 50 °C. The steel wheel had a diameter of 203.2 mm and it is capable of applying a load equal to 705 ± 4.5 N. The specimens were subjected to 52 ± 2 passes per minute with a maximum speed of approximately 0.305 m/s, reaching the midpoint of the samples. The final measurement corresponded to the deformation caused by the wheel. The failure criteria considered the achievement of a 20 mm rut depth or 20,000 passes. Fig. 6 reports the graph of the Hamburg wheel track test for each mixture.

For a proper understanding of the value, the results of the test are reported based on the standard deviation. The Wheel tracker machine is set to stop when the standard deviation between the two samples exceeds 1 mm. From Fig. 6 it can be noticed that Mix3 reaches the lower rut depth and the higher number of passes. The better performance of Mix3 can be connected to the presence of bitumen. Mix2 has a different behaviour compared to Mix1 and Mix3 and it is due to the presence of CDW aggregates that have higher water sensitivity. Furthermore, Mix2 has a higher porosity and so lower structural properties.

3.9. *Vertical permeability of the samples*

Through the vertical permeability test, it was possible to determine the interconnection level of the air voids in terms of permeability. This test allowed the evaluation of the direct parameter that represents the drainage performance of the asphalt mixtures. The vertical permeability test has been performed on 3 samples for each mixture. The vertical permeability was tested in compliance with the European standard EN 12697–19, by measuring the vertical flow of water through the

Table 10
Average results of the vertical permeability of each mixture.

Mechanical values	Unit	Mix1	Mix2	Mix3
Air voids content	**V_a [%]**	18.9 (±0.87)	25.2 (±1.03)	17.6 (±0.51)
Mean Vertical Permeability	**K_v [m/s]**	2.1×10^{-3} (±0.0004)	2.5×10^{-3} (±0.0001)	2.9×10^{-3} (±0.0002)

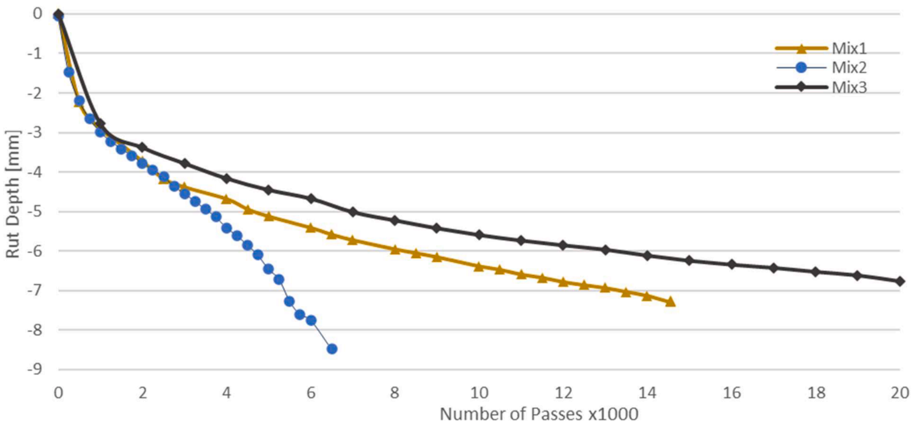

Fig. 6. Hamburg curve for Mix1 with Stripping Inflection Point.

Table 11
PTV results for Mix1, Mix2, and Mix3.

Mixtures	Unit	PTV
Mix1	**PTV**	55 (±4)
Mix2	**PTV**	51 (±4)
Mix3	**PTV**	77 (±3)

specimens. The average results of the vertical permeability of each mixture are reported in Table 10.

Despite the lower air voids content, Mix3 has higher vertical permeability. Thus, the air voids in Mix3 are more interconnected than in the other two mixtures, allowing a better permeability. This could be linked to the different mastic generated by the polyolefin-based synthetic transparent binder. Nonetheless, the European standard suggested typical values of the vertical permeability between $0,5 \times 10^{-3}$ and 3.5×10^{-3} m/s, and the experimental mixtures fall in this range. A small difference is recorded between Mix1 and Mix2 despite the considerably higher porosity of the latter one.

3.10. *Skid resistance test*

By determining the skid resistance of the three studied mixtures, it was possible to evaluate their surface performance and thus the friction response. The skid resistance has been measured using the British Pendulum tester, following the procedure suggested by the EN 13036–4 standard. The surface characteristic was defined by a dimensionless parameter, PTV. The PTV results are reported in Table 11.

Usually, PTV values range from 37, which indicates a bad microtexture to 70–80 units for good friction properties [31]. According to some Italian technical specifications, PTV>50 represents a suitable value for new bituminous surfaces. The average results obtained for Mix1 and Mix2 lean around this minimum requirement showing adequate skid resistance. Mix3 has a higher PTV value due to the presence of a bituminous binder instead of the synthetic one. In Mix2 the lower PTV is mainly related to the use of CDW aggregates, which confers a different texture to the surface. Hence, the type of binder and the shape of aggregates are factors that play a key role in the friction response of wearing courses.

4. Conclusions

Due to local climate change, well-being and human health are current concerns in modern cities. In the road sector, governments are promoting more advanced and sustainable technologies aimed to create a more pleasant environment. The construction of low-impact pavements such as cool and recycled pavement is a solution for sustainable development, without compromising their safety and efficiency. The present study has been conducted to assess the properties of innovative materials that could be employed for producing low-impact porous wearing courses. A polyolefin-based synthetic transparent binder and recycled aggregates produced from construction and demolition waste were used and compared to a traditional bituminous porous asphalt. From the findings of the laboratory investigation, it is possible to delineate the following conclusions:

- The use of CDW aggregates of a specific size, tends to increase the percentage of air voids in the mixture. It was possible to obtain a higher air voids content and a better vertical permeability. The use of the innovative polyolefin-based synthetic transparent binder does not result in any deterioration of the volumetric properties of the mixtures;
- In terms of statical and mechanical performances it is possible to conclude that the mixtures with the polyolefin-based synthetic transparent binder have higher cohesion and stiffness if compared to the reference bituminous mixture. Furthermore, the substitution of virgin aggregates with CDW aggregates increases the mechanical properties of the porous asphalt, making the mixture less thermosensitive;
- The polyolefin-based synthetic transparent binder worsens the water susceptibility of the asphalt concrete. As a consequence, the reduction of cohesion and rutting resistance is amplified in water conditions. This phenomenon is further intensified when CDW aggregates are used as aggregates due to the higher porosity of the mixture and the higher water sensitivity of the recycled material.

Future tests will evaluate the fatigue life of the different materials. All in all, based on these preliminary and promising results, the use of the polyolefin-based synthetic transparent binder can be considered a suitable and valid solution for the production of low-impact pavements for urban areas. However, the addition of CDW at high percentage needs to be optimized in order to limit the water damage behaviour of the mixture.

CRediT authorship contribution statement

Beatrice De Pascale: Conceptualization, Data curation, Formal analysis, Investigation, Validation, Writing – original draft, Software. **Piergiorgio Tataranni:** Conceptualization, Validation, Project administration, Supervision, Writing – review & editing. **Claudio Lantieri:** Conceptualization, Validation, Supervision, Writing – review & editing. **Alessandra Bonoli:** Conceptualization, Validation, Supervision, Writing – review & editing. **Cesare Sangiorgi:** Conceptualization, Validation, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

References

[1] M. Carpio, Á. González, M. González, K. Verichev, Influence of pavements on the urban heat island phenomenon: A scientific evolution analysis, Energ. Buildings 226 (2020), 110379, https://doi.org/10.1016/J.ENBUILD.2020.110379.

[2] X. Guan, J. Wang, F. Xiao, Sponge city strategy and application of pavement materials in sponge city, J. Clean. Prod. 303 (2021), 127022, https://doi.org/10.1016/J.JCLEPRO.2021.127022.

[3] H.E. Gilbert, P.J. Rosado, G. Ban-Weiss, J.T. Harvey, H. Li, B.H. Mandel, D. Millstein, A. Mohegh, A. Saboori, R.M. Levinson, Energy and environmental consequences of a cool pavement campaign, Energ. Buildings 157 (2017) 53–77, https://doi.org/10.1016/j.enbuild.2017.03.051.

[4] P. Tang, L. Mo, C. Pan, H. Fang, B. Javilla, M. Riara, Investigation of rheological properties of light colored synthetic asphalt binders containing different polymer modifiers, Constr. Build. Mater. 161 (2018) 175–185, https://doi.org/10.1016/J.CONBUILDMAT.2017.11.098.

[5] J.W. Shaw, M.V. Chitturi, D.A. Noyce, Special-color pavement marking for highway work zones literature review of international practices, Transp. Res. Rec. 2617 (1) (2017) 78–86.

[6] D.M. Senevirathne, V.M. Jayasooriya, S.M. Dassanayake, S. Muthukumaran, Effects of pavement texture and colour on Urban Heat Islands: An experimental study in tropical climate, Urban Clim. 40 (2021), 101024, https://doi.org/10.1016/J.UCLIM.2021.101024.

[7] F. Jin, Study on color pavement layout of expressway service area, IOP Conf. Ser.: Earth Environ. Sci. 638 (1) (2021) 012008.

[8] S. Garré, S. Meeus, H. Gulinck, The dual role of roads in the visual landscape: A case-study in the area around Mechelen (Belgium), Landsc. Urban Plan. 92 (2009) 125–135, https://doi.org/10.1016/j.landurbplan.2009.04.001.

[9] M. Santamouris, Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments, Renew. Sustain. Energy Rev. 26 (2013) 224–240, https://doi.org/10.1016/J.RSER.2013.05.047.

[10] R. Naus, J. Voskuilen, Light Coloured Asphalt, in: Czech Technical University in Prague - Central Library, 2017. https://doi.org/10.14311/ee.2016.409.

[11] G.D. Airey, M.H. Mohammed, C. Fichter, Rheological characteristics of synthetic road binders, Fuel 87 (2008) 1763–1775, https://doi.org/10.1016/j.fuel.2008.01.012.

[12] C. Fuentes-Audén, F.J. Martínez-Boza, F.J. Navarro, P. Partal, C. Gallegos, Formulation of new synthetic binders: Thermo-mechanical properties of recycled polymer/oil blends, Polym. Test. 26 (2007) 323–332, https://doi.org/10.1016/j.polymertesting.2006.11.002.

[13] K. Seifeddine, S. Amziane, E. Toussaint, Experimental investigation of physical characteristics to improve the cooling effect of permeable pavements, Constr. Build. Mater. 345 (2022), 128342, https://doi.org/10.1016/J.CONBUILDMAT.2022.128342.

[14] I. Kousis, C. Fabiani, A.L. Pisello, Could a bio-resin and transparent pavement improve the urban environment? An in field thermo-optical investigation and life-cycle assessment, Sustain. Cities Soc. 79 (2022) 103597.

[15] R. Silva, A.C. Carvalho, S.C. Pereira, D. Carvalho, A. Rocha, Lisbon urban heat island in future urban and climate scenarios, Urban Clim. 44 (2022), 101218, https://doi.org/10.1016/J.UCLIM.2022.101218.

[16] W. Yue, X.Y. Ye, J. Xu, L. Xu, J. Lee, A brightness–darkness–greenness model for monitoring urban landscape evolution in a developing country – A case study of Shanghai, Landsc. Urban Plan. 127 (2014) 13–17, https://doi.org/10.1016/J.LANDURBPLAN.2014.04.010.

[17] I. Kousis, C. Fabiani, L. Ercolanoni, A.L. Pisello, Using bio-oils for improving environmental performance of an advanced resinous binder for pavement applications with heat and noise island mitigation potential, Sustainable Energy Technol. Assess. 39 (2020), 100706, https://doi.org/10.1016/J.SETA.2020.100706.

[18] S.R.O. Aletba, N. Abdul Hassan, R. Putra Jaya, E. Aminudin, M.Z.H. Mahmud, A. Mohamed, A.A. Hussein, Thermal performance of cooling strategies for asphalt pavement: A state-of-the-art review, Journal of Traffic and Transportation Engineering (English Edition) 8 (2021) 356–373, https://doi.org/10.1016/J.JTTE.2021.02.001.

[19] T. Knappenberger, A.D. Jayakaran, M. Asce, J.D. Stark, C.H. Hinman, Monitoring Porous Asphalt Stormwater Infiltration and Outflow (2017), https://doi.org/10.1061/(ASCE)IR.1943.

[20] H. Li, H. Xu, F. Chen, K. Liu, Y. Tan, B. Leng, Evolution of water migration in porous asphalt due to clogging, J. Clean. Prod. 330 (2022) 129823.

[21] Z. Zhang, A. Sha, X. Liu, B.o. Luan, J. Gao, W. Jiang, F. Ma, State-of-the-art of porous asphalt pavement: Experience and considerations of mixture design, Constr. Build. Mater. 262 (2020) 119998.

[22] R.V. Silva, J. de Brito, R.K. Dhir, Use of recycled aggregates arising from construction and demolition waste in new construction applications, J. Clean. Prod. 236 (2019) 117629.

[23] B. Gómez-Meijide, I. Pérez, Recycled aggregates (RAs) for asphalt materials, in: Handbook of Recycled Concrete and Demolition Waste, Elsevier Inc., 2013, pp. 378–393, https://doi.org/10.1533/9780857096906.3.378.

[24] A.J. Roque, P.F. da Silva, G. Rodrigues, R. Almeida, Recycling of CDW and Steel Slag in Drainage Layers of Transport Infrastructures, Procedia Eng. 143 (2016) 196–203, https://doi.org/10.1016/J.PROENG.2016.06.025.

[25] S. Pourkhorshidi, C. Sangiorgi, D. Torreggiani, P. Tassinari, Using Recycled Aggregates from Construction and Demolition Waste in Unbound Layers of Pavements, Sustainability (Switzerland). 12 (2020) 1–20, https://doi.org/10.3390/su12229386.

[26] C. Sangiorgi, C. Lantieri, G. Dondi, Construction and demolition waste recycling: An application for road construction, Int. J. Pavement Eng. 16 (2015) 530–537, https://doi.org/10.1080/10298436.2014.943134.

[27] C. Maduabuchukwu Nwakaire, S. Poh Yap, C. Chuen Onn, C. Wah Yuen, H. Adebayo Ibrahim, Utilisation of recycled concrete aggregates for sustainable highway pavement applications; a review, Constr. Build. Mater. 235 (2020), 117444, https://doi.org/10.1016/J.CONBUILDMAT.2019.117444.

[28] J.R. Jiménez, F. Agrela, J. Ayuso, M. López, Estudio comparativo de los áridos reciclados de hormigón y mixtos como material para sub-bases de carreteras, Materiales de Construccion. 61 (302) (2011) 289–302.

[29] A.I. Kareem, H. Nikraz, H. Asadi, Performance of hot-mix asphalt produced with double coated recycled concrete aggregates, Constr. Build. Mater. 205 (2019) 425–433, https://doi.org/10.1016/J.CONBUILDMAT.2019.02.023.

[30] J.J. Galan, L.M. Silva, I. Pérez, A.R. Pasandín, Mechanical Behavior of Hot-Mix Asphalt Made with Recycled Concrete Aggregates from Construction and Demolition Waste: A Design of Experiments Approach, (n.d.). https://doi.org/10.3390/su11133730.

[31] P. Kotek, M. Kováč, Comparison of Valuation of Skid Resistance of Pavements by two Device with Standard Methods, Procedia Eng. 111 (2015) 436–443, https://doi.org/10.1016/J.PROENG.2015.07.113.