scientific reports

OPEN

Chemical properties of peat micro particles modified asphalt

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This study investigated the chemical properties of peat microparticles modified asphalt (Pt.M.A.). The originality of the study resides in the examination of the chemical characteristics of peat microparticles (Pt.) modified asphalt (Pt. M.A.) utilising FTIR, SEM, SFE, and XRD methodologies. This encompasses Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), surface free energy (SFE), and X-ray diffraction (XRD). Initially, FTIR examined the functional groups of both unaltered and altered asphalt binders. The SEM images reveal improved compatibility, showcasing superior diffusion of the modifier across the asphalt. A further critical factor is that improved adhesion properties, according to the SFE study, indicate that modified binders generally offer more SFE compared to unmodified binders. The XRD measurements revealed a semi-crystalline structure in the Pt. modifier and an amorphous structure in the basal asphalt binder. The integration of Pt. into the asphalt cement resulted in modifications to the phases of both constituents, culminating in the emergence of a new semi-crystalline phase inside the modified asphalt binder. These data suggest that peat microparticles (Pt.) can improve the efficacy of asphalt binders by enhancing compatibility, adhesion, and resistance to ageing.

Keywords FTIR, SFE, SEM, XRD, Modified asphalt, Chemical properties

Asphalt is extensively used in the construction of roads and highways as a crucial material with several functional qualities, encompassing physical, chemical, morphological, rheological, and mechanical characteristics[1–4]. At now, the main use of asphalt is as a binding agent in asphalt paving[5–7]. Additionally, this involves the amalgamation of asphalt and aggregates to create an asphalt mixture[8], often achieved by a hot mixing procedure at high temperatures of 160 °C[9]. Although other processes like foamed, heated, or cold mix technology are available[10,11], they are not widely used and only contribute to a small percentage of total asphalt production[12–15]. In another essential point, to improve the durability and general effectiveness of asphalt[16–19], companies use supplementary processing procedures[20]. This process involves the manipulation of several variables, such as the combination of different binding agents, the careful selection of specialised techniques and chemical catalysts, and the incorporation of modifying chemicals. Refineries optimise these factors to produce bitumen that meets the industrial requirements while minimising production costs and recycling waste materials. This process involves the manipulation of several variables, such as the combination of different binding agents, the careful selection of specialised techniques and chemical catalysts, and the incorporation of modifying chemicals. Refineries optimise these factors to produce bitumen that meets the industrial requirements while minimising production costs and recycling waste materials[21,22]. To fully understand the behaviour of asphalt, it is essential to analyse its chemical composition and its interactions with various chemicals[23–25], including modifiers and additives[26–28].

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Therefore, the techniques necessary to develop HMA based on complicated behaviours should be understood to enhance the chemical properties of the asphalt by utilising modifiers[29]. The asphalt mixtures are sensitive to oxygen, ozone, and chemicals that are exposed during the preparation, storage, and service. Similarly, the durability of asphalt mixtures depends on two main factors: resistance to age hardening and resistance to oxidation damage. Micropeat particles (Pt.) reach in carbon with more than 85%; therefore, it works as antioxidants to control the age-hardening of asphalt mixtures. Oxidation is regarded as one of the major distresses in asphalt pavement; it is the accumulation of permanent deformation in asphalt caused by repeated loads at high working temperatures[30]. Oxidation affects the pavement ride quality and leads to serious safety issues for road users; permanent deformation in pavement can cause uncontrollable vehicle sliding with a high potential for traffic accidents[31].

Recently, there has been significant interest in modified asphalt due to the growing demand and pressing need to improve its performance and longevity[32–36]. The rheological changes associated with the ageing of Pt.M.A. are linked to a breakdown of the molecular structure of the binders to form a lower molecular weight peat structure. Based on the SHRP parameters, adding Pt decreases rutting for the binder at high temperatures. Rheological properties indicated that 5% Pt is the optimum content as a modifier with asphalt[37]. Modifications to the asphalt binder, achieved through the addition of peat at various concentrations, demonstrably enhanced its physical properties. Improvements in penetration, ductility, and material distribution within the binder demonstrated this. Specifically, the incorporation of the peat led to increased resistance to volumetric changes and enhanced hardness, indicating a more stable and durable binder[37]. Analysis indicates peat-modifying asphalt enhances resistance to temperature-induced variations and hardness increases[38,39]. Moreover, chemical characteristics of micropeat particles Pt. with asphalt (Pt.M.A.), while comparing them to untreated asphalt as a reference. The study also used analytical methods, such as Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), surface free energy (SFE), and X-ray diffraction (XRD). Micropeat particles enhance the characteristics of asphalt binder, such as compatibility, adhesion, and resistance to ageing. Additionally, this interaction achieving a strong and durable bond occurs from modified asphalt binder. In the presence of water, the quality of this bond becomes even more critical as it helps to resist moisture damage and maintain the structural integrity of the pavement[40]. For instance, the bituminous binder's adhesive properties enable it to firmly adhere to the aggregate particles, providing cohesiveness to the overall mixture. Simultaneously, the binder's waterproofing characteristics create a protective barrier against moisture infiltration[41].

Conversely, the extensive scale and considerable expenses involved in repairing and revitalising the transportation infrastructure of a nation, coupled with ongoing environmental and political concerns regarding the utilisation and acquisition of petroleum resources, have generated a growing interest in the development and qualification of novel asphalt mixtures. This interest stems from the demand to explore sustainable alternatives and efficient methods for constructing and maintaining roadways[42,43]. Similarly, this variation occurs even within a few micrometres from the bitumen-air surface, which is particularly susceptible to the influence of environmental factors[44–46]. In the same way, the objective of this research is to assess the efficacy of peat microparticles in enhancing the performance of asphalt binders. This study offers a thorough examination of the chemical characteristics and performance improvements resulting from the inclusion of peat microparticles in modified asphalt. We anticipate that the anticipated results will significantly impact the field of pavement engineering, offering crucial insights into the development of asphalt binders with improved durability, efficiency, and ecological sustainability. The objective of this project is to use sophisticated analytical techniques to provide the basis for future advancements in road building materials. This project aims to enhance the quality and longevity of infrastructure. The results of this research are anticipated to greatly influence the area of pavement engineering, specifically in the advancement of longer lasting and more effective asphalt binders for road building.

On the other hand, comprehensive of the chemical properties and performance improvements that arise from the incorporation of peat microparticles into asphalt, and examine the functional groups found in chemical bonding inside the asphalt sample in both unaltered and altered asphalt binders[47]. Hence, the hypothesis is that adding peat microparticles to the asphalt might possibly modify its chemical composition, hence improving the performance of the asphalt. Therefore, materials with increased surface energy exhibit a greater attraction to surfaces, hence enhancing the contact and adhesion between the asphalt binder and aggregates[48]. The adhesive qualities of the modified asphalt are anticipated to exhibit elevated surface free energy (SFE) values in comparison to the unmodified ones, signifying improved adhesion qualities[49]. After analysing (SEM) the structure and arrangement of small peat particles inside the asphalt matrix, pictures provide essential information about the physical distribution and possible chemical interaction between the modifier and the asphalt. Increased dispersion of the modifier indicates enhanced compatibility of the modified asphalt[50–52]. The alteration in crystal structure by microparticles examined improved the performance of the asphalt binder and induced a semi-crystalline phase in the modified asphalt binder, potentially resulting in the formation of a new state[53]. Hence, the importance of this research lies in its ability to meet the increasing demand for environmentally friendly and high-quality materials in the building sector[54]. By including innovative additives like peat micro particles, it is possible to enhance the effectiveness of asphalt binders. This might potentially result in substantial improvements in road longevity, decreased maintenance costs, and an overall upgrade in infrastructure quality. Moreover, the use of peat, an abundant and renewable natural resource, aligns with the global emphasis on sustainable development and the reduction of environmental damage[55,56]. The addition of peat microparticles to asphalt binder will significantly enhance its chemical properties, leading to improved compatibility, adhesion, and resistance to aging. This aims to further the development of environmentally friendly solutions in the construction sector by examining the chemical properties and performance benefits of asphalt treated with peat.

Chemical properties of the materials

Several experiments were conducted to examine the fluctuations and how the incorporation of peat microparticles influences the chemical properties of asphalt binder, specifically in terms of compatibility, adhesion, and resistance to aging. The novelty of this work lies in its comprehensive investigation of the chemical properties and performance enhancements of asphalt binder modified with peat microparticles. Specifically, the study utilises a combination of advanced analytical techniques, Vacillations and oscillations in the chemical composition of the basic asphalt binder and the effects of adding Pt. were assessed using a scanning electron microscope (SEM), surface free energy (SFE), a roentgenogram diffractometer (XRD), and Fourier transform infrared spectroscopy (FTIR). The key aspect discussed deep into anticipated enhancing our understanding of the potential advantages of Pt as a performance modifier for asphalt binder. Moreover, characterise the modified asphalt and elucidate the interactions between peat and asphalt at a molecular level by this multi-faceted approach and comprehensively analyse the modified asphalt and achieve the desired performance enhancements. A multi-faceted approach confirms the successful incorporation of the modifier and elucidates all interactions with the asphalt at a molecular level. This approach will provide valuable insights into the modification mechanism and its potential for long-term durability. In the same way, visualises the dispersion of the modifier within the asphalt matrix, revealing agglomeration or inconsistencies, and identifies microcracks and voids to study the modifier's overall integrity and ability to be a modifier with asphalt. Finally, providing insights into the crystalline structure to assess any changes induced by the peat as a modifier, also analyses the performance characteristics such as oxidation and high-temperature behaviour. The combined analytical approach guarantees the composition, microstructure, and properties of the modified asphalt, ultimately guiding the development of high-performance Pt-modified asphalt.

Sample preparation

The characteristics of peat indicate that it is a mastic or adhesive substance when wet, while it becomes brittle and ranges from brown to black when dry, exhibiting a very light weight[39,57–65]. The asphalt containing an adequate percentage of Pt was subjected to a 200 mm mesh or 75 µm sieve, which enhanced the characteristics of the asphalt[37,39,66]. We heated the asphalt binder to 110 °C in an oven for 30 min, then blended it in a mould using a high shear mixer until we achieved homogeneity, as confirmed by testing for the homogeneity point[38,39]. The modified binders utilised in this study were created by amalgamating the original 80/100 asphalt with peat (Pt.M.A.). We refer to this method as the 'Wet Process' because we incorporate the addition into the asphalt.

The unaltered penetration grade asphalt 80/100 (original or control) was combined with the additive to create three supplementary binders: 3%, 5%, and 7%, contingent upon the binder composition. The combination of peat and asphalt was performed using a high-shear mixer. Table 1 delineates the mixing parameters used in the blending process. After evenly dispersing the Pt particles throughout the mixing process, we held the asphalt at 160 °C for one hour. Peat particles were included in the asphalt binder to augment its rigidity and elastic properties and thereafter mixed with aggregates utilising a wet method. We evaluated all samples, with varying mixing durations, to determine the binder's softening point. We established this technique to achieve a dispersive mixing of asphalt and Pt, which involved delivering a constant shear of 3500 rpm for two hours. To comprehend the modification process, approximately 50 g of binder were collected and preserved for the softening point test every 20 min. Peat particles interact with asphalt, enhancing its stiffness and elastic characteristics until it reaches optimal performance. When the apparent value in this test reaches a plateau level after a consistent upward trend, it is considered the peak in practical applications of binders[67]. The blending technique necessitates heating the specified quantity of asphalt to 160 °C in the oven for approximately 30 min. A minimum of 1 L of asphalt per blend is required. We place the asphalt in a container, heat it on a hot plate, and then subject it to a high shear mixer. We fully submerge the dispersion head in the hot asphalt and subject it to low shear mixing at 500 rpm until we achieve the desired temperature. Once the temperature reaches equilibrium, we gradually introduce peat, increase the mixing speed to 3500 rpm, and initiate the blending period. Point of Homogeneity We produced modified asphalt formulations that incorporated grade Pt. and asphalt, enabling the quantification of the total input amount at each percentage[68]. We conducted a softening point test for the binder on the samples, applying a steady shear of 3500 rpm for two hours to achieve a dispersive mixing of asphalt and Pt. We extracted and preserved approximately 20% of the total binder additive for the softening point test every 20 min to understand the modification process[38].

Fourier transform infrared spectroscopy

Fourier transform infrared spectroscopy (FTIR) is a beneficial technique due to minimal sample preparation requirements[69]. FTIR spectroscopy is an analytical technique for the presence of solvent in asphalt samples due to the simplicity of implementation. To facilitate analysis, a w/w asphalt solution in carbon disulphide is prepared

Asphalt weight (g)	PEAT Percentages of asphalt	PEAT Weight (g)	Total weight(g)	Mixing time (min)	Mixing speed (rpm)	Mixing temperature (°C)	Asphalt weight (g)
500	0%		0	500	–	–	–
500	3%		15.5	515.5	0-120	3500 ± 10	160
500	5%		26.3	526.3	0-120	3500 ± 10	160
500	7%		37.6	537.6	0-120	3500 ± 10	160

Table 1. Blending binder protocol.

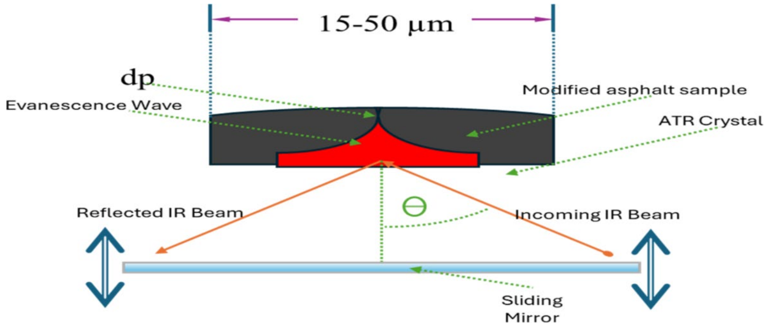

Fig. 1. Schematic of Fourier transform infrared spectroscopy (FTIR).

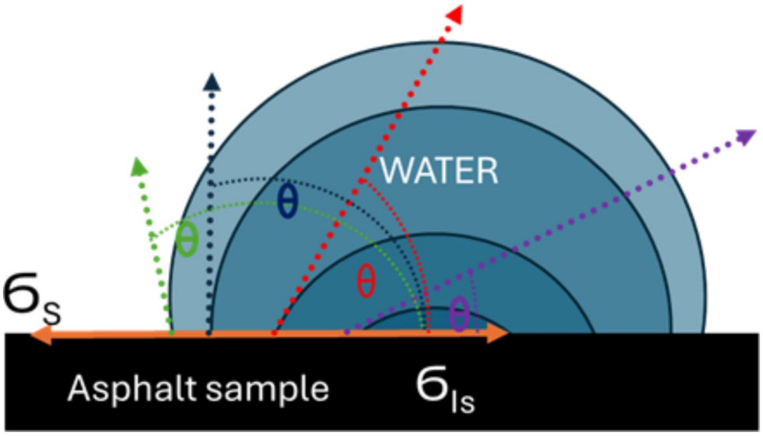

Fig. 2. The contact angle with one or more asphalt sample.

and analysed alongside a blank solvent using circular sealed cells. Spectra will be obtained with 32 scans and a resolution of 4 cm1 in the 500–4000 cm1 wavelength range. Due to the severe oxidation process induced by the RTFO test, the analysis of functional and structural changes in asphalt binders has been demonstrated following the schematic of Fourier transform infrared spectroscopy (FTIR) as shown in Fig. 1.

Analyses the surface of a sample with a penetration depth of approximately 0.1 to 1 micron. The analysis area can range from as small as 15–50 m to larger areas. As shown in diagram 1, Fig. 1 demonstrates the setup of ATR-FTIR for analysing a modified asphalt sample. The sample of modified asphalt is placed in close contact with the ATR crystal, and the IR beam arrives at the crystal at a specific inclination of incidence (θ) greater than the parameter of the critical angle, resulting in total internal reflection at the crystal-sample interface. Another essential point, the evanescent wave, occurs in an interaction with the Pt. M. A. sample. To elaborate, the reflected infrared (IR) beam conveys spectral information about the surface of the sample.

Surface free energy

Materials with high surface energy have a greater affinity for surfaces, while materials with low surface energy impede this contact. The surface energy of asphalt binders was measured using a contact angle goniometer and drop image standard software, with distilled water serving as the probe liquid. The SFE test was conducted at 25 °C to assess the contact angle and 0.5 ml/s of pure drop of refined water. The cross-section of a water droplet on an asphalt sample focuses on the interaction between water and an asphalt sample, with a particular emphasis on the contact angle and potential tension force. In Fig. 2 illustrates a droplet forms a curved interface with the asphalt surface, and the angle between the tangent to the interface and the asphalt surface is represented as θ (theta). While asphalt has θ larger than 90⁰ means a big angel has less contact surface, and the aim of modification the asphalt to have a surface that is able to drain the water more rapidly than the conventional asphalt. In the same way, an asphalt surface with θ less than 90° means a small angle has a larger contact surface, resulting in less efficient water drainage compared to the modified asphalt. In essence, increasing the contact angle (θ) to a value greater than 90° in modified asphalt achieves a hydrophobic surface, promoting faster water runoff and reducing the risk of hydroplaning. Conversely, an unmodified asphalt surface with smaller contact angles ($\theta < 90°$) is more hydrophilic, leading to increased water retention and material segregation. Consequently, the water has the highly ability to penetrate between the aggregate and the coating film of the asphalt and tends to hold onto water, increasing the probability of decreased traction and skidding. However, the aim is to evaluate the impact of binder surface energy on the moisture damage resistance of asphalt mixtures by deducting the behaviour of water with the asphalt surface[49].

Electron microscopy scanning

The morphology of the exterior of both the blank peat asphalt binder and the chemically modified peat asphalt binder with different amounts of dispersing agent was analysed using scanning electron microscopy (SEM). Figures 3 and 4 show the operating schematic SEM after the sample was coated. The objective was to classify particle clusters according to their chemical composition and form, examine the correlation between these factors, and assess any variations. We acquired scanning electron microscopy (SEM) images using a gaseous secondary electron detector (GSE) at an accelerating voltage of 30 kV. We directly introduced uncoated, non-conductive specimens into the microscope chamber for imaging. Imaging visualises the dispersion of peat within the asphalt matrix, revealing any agglomeration or inconsistencies that affect the mixture's performance. microscopic analysis also to identify micro-cracks and voids to increase valuable information about peat-modified asphalt overall integrity and potential failure points and extracted components to study the behaviour of modified asphalt in the long-term performance.

X-ray diffraction (XRD) analysis

X-ray diffraction (XRD) is a well-established and crucial experimental method utilised to investigate the crystal structure of solid materials. The technique's versatility stems from its non-destructive nature and ability to analyse a wide range of materials. Therefore, determination of lattice parameters for unidentified materials is possible. The crystallographic alignment in both single-crystal and polycrystalline materials is a relevant factor. This method of analysis is applied to materials in powder form, manufactured parts, fibres, coatings and wafers. Measurements and data collection are obtained by reflection, transmission, and sweeping angle. Temperature experiments allow phase transitions for each crystalline structure present in the material[70]. The specimen's crystalline phase diffraction pattern identifies as well as determines the sample's structural properties. Nevertheless, non-destructive and the technique used for investigating materials' properties, such as residual stress.

Results and discussion

Morphology and components of pt. M. A

The SEM employs a concentrated electron beam to interact with the surface of a solid specimen, producing multiple signals that reveal information about its properties. The derived images are from a scanning electron microscope (SEM) equipped with an energy-dispersive X-ray spectroscopy (EDS) detector.

Figure 5; Table 2 illustrate the use of scanning electron microscopy (SEM) to analyse unmodified asphalt binder, providing a baseline to assess changes and effects induced by modifiers and using dwell time of 0.1 msec and sweep count of 50, and electron high tension EHT of 20.00 kilovolts, indicating the acceleration voltage of the electron beam. Working Distance: the distance between the sample and the objective lens is 7.5 mm. Hence, magnification 500X, which means the image is magnified 500 times the actual size of the sample. The top-left image labelled with IMG1 as a secondary electron image providing topographical information about the sample surface also reveals a rough surface with a distinct feature that covers a 1.0 mm field of view. In the same way, each elemental map scale 50 µm scale bar except for the Au map shares the 1.0 mm scale mutual with the first image.

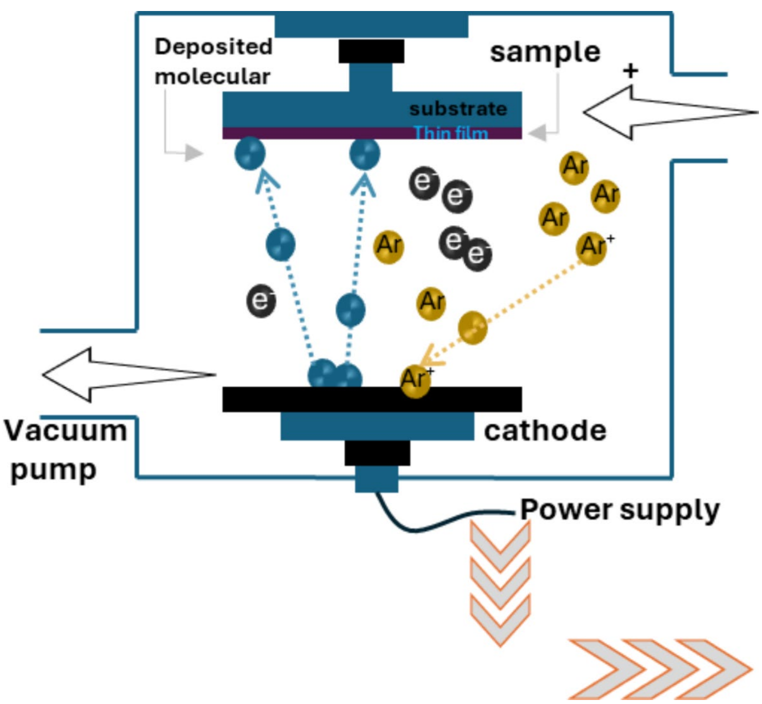

Fig. 3. Schematic specimens coating.

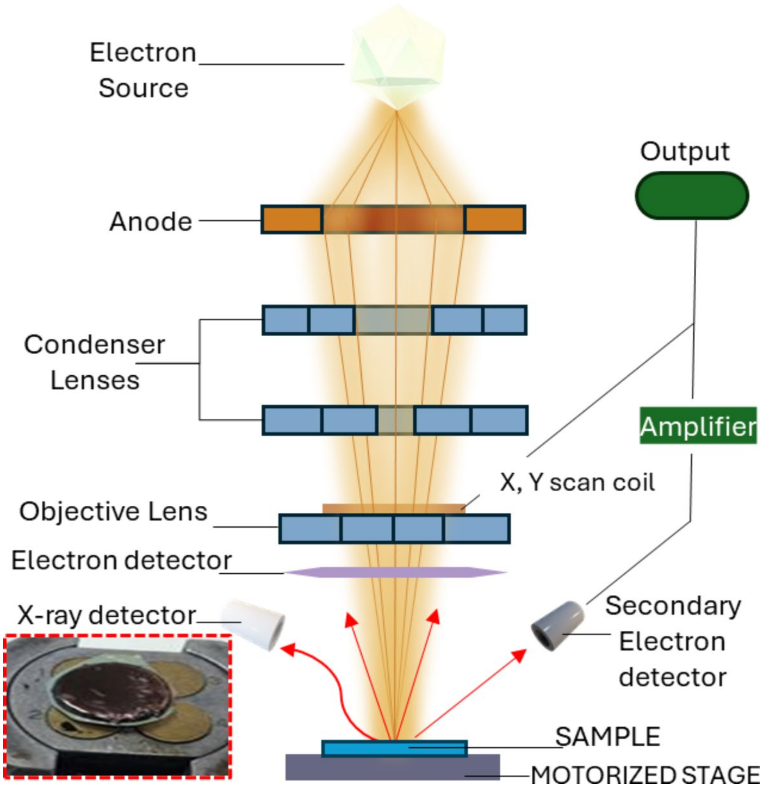

Fig. 4. Operating schematic SEM.

Carbon and oxygen are widely distributed across the sample surface. The most concentrated concentrations of silicon Si and sulphur S were found to be associated with distinct particles. Fly ash, a prevalent constituent of coal-bearing rock strata, primarily comprises silicon dioxide, aluminium oxide, and calcium oxide. Scanning electron microscopy analysis reveals a morphology characterised by hollow, spherical particles[71]. This differs from metakaolin (MK), which typically exhibits porous, angular, platy particles with sizes ranging from 1 to 20 µm. Batu Pahat soft clay, with particle sizes between 9.49 and 14 µm, demonstrates uniform dispersion within an asphalt matrix, potentially indicative of excellent asphalt binder performance. The elemental composition of BPSC, which includes sodium, chlorine, silicon, and sulphur, contributes to its high expansion pressure[7,72–74].

Analysis electron images

Additive induces a considerable modification in the internal microstructure of blended asphalt through the combining of Pt., as evidenced by the well-dispersed distribution of the modifier throughout the asphalt, in contrast to the unmodified binder[75]. We observe the potential for both physical dispersion and chemical reactions between Pt and asphalt. Figures 6 and 7 illustrate that incorporating modifiers, including Pt., leads to an increase in the shear modulus of asphalt cement. The observed increase might be associated with improved resistance to rutting damage compared to the unmodified asphalt.

Scanning electron microscopy (SEM) images are presented at a single magnification. Image (a) shows a crystalline structure, appearing uniform and homogeneous. Picture (a) depicts what seems to be a uniform and homogenous crystalline structure. In image (b), it is crystal clear how the process of incorporating micro-Pt. alters the internal composition of the blended asphalt. Under scanning electron microscopy (SEM), the asphalt phase is black and seems inflexible, but the Pt. phase is bright and perhaps flexible. The modified asphalt stands out from the original asphalt due to its noticeable morphological variations. The outside element layer of peat particles has elements such as sodium, chlorine, silicon, and sulphur, which produce significant expansion exertion. Similarly, the asphalt binder's calcium, magnesium, and ammonium ions function as exchangeable cations. Chemical processes cause the Pt. to break down into tiny pieces. In a similar study, the presence of exchangeable cations, such as Ca2+, Mg2+, and ammonium, may facilitate the dispersion of BPSC microparticles within the asphalt binder. This observation is consistent with previous research that linked increased homogeneity of modified slag grains to elevated sulphur content[76,77].

Table 3 displays scanning electron micrographs (SEMs) of Pt particles embedded in an asphalt matrix, showing enhanced compatibility and storage stability at high temperatures as compared to unmodified asphalt. Particles of Pt have broken surfaces and sharp angles, giving them an amorphous appearance. The manufacturing process of the particles may have prevented the observation of thin-layered particles[78].

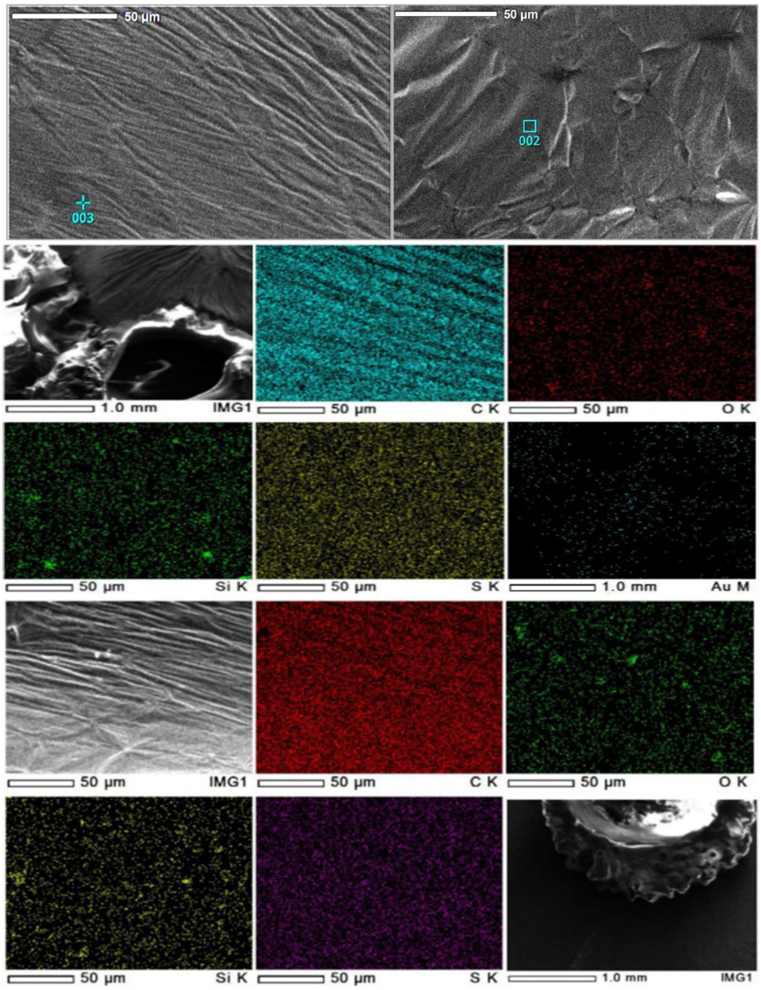

Fig. 5. Electron images of unmodified for one magnification 700X.

Elements	(KeV)	Mass %	Error %	AL %	k
C	0.277	86.93	0.16	92.41	87.412
0	0.525	5.39	1.23	4.30	3.6831
AI	1.486	1.63	0.35	0.77	2.7466
Si	1.739	1.89	0.39	0.86	3.4717
S	2.307	4.16	0.39	1.66	8.4064
Total		100.00		100.00	100.00
Pt	2.048	2.73	1.83	0.18	3.647

Table 2. Quantitative analysis using the ZAF method, yielding a fitting coefficient of 0.4439.

Fourier transform infrared spectroscopy

The results indicate changes in chemical bonding within the asphalt binder following RTFO aging. Infrared (IR) absorbance data suggests the complex formation of Pt.M.A. affected by the specific exchangeable cation found in the Pt. The spectra of (FTIR) the unmodified and Pt. modified asphalt binders are illustrated in Fig. 8; Table 4. We use the ratio of absorbance for each Pt. to measure the relative amount of asphalt that has adsorbed onto the Pt. particles. The Pt. complex, when isolated from the asphalt binder, demonstrates comparable characteristics after undergoing chemical treatment. Similarly, micro Pt. complexes show equivalent performance to the modified asphalt-organic mineral complexes. Therefore, Fig. 8; Table 4 present FTIR spectra of the base and Pt.-modified asphalt binders. Details the relationship between relative intensity, vibration type, functional group, and frequency (cm2) for various chemical bonds.

The ratio of absorbance for each Pt is used as a relative measure of asphalt adsorbed onto the Pt. particles. We classify the relative intensity into very weak (vw), weak (w), moderate (m), strong (s), and very strong (vs.).

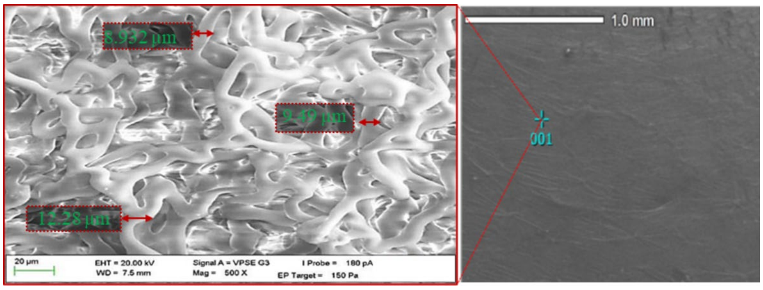

Fig. 6. Electron microscopy images of the modified material at a single magnification.

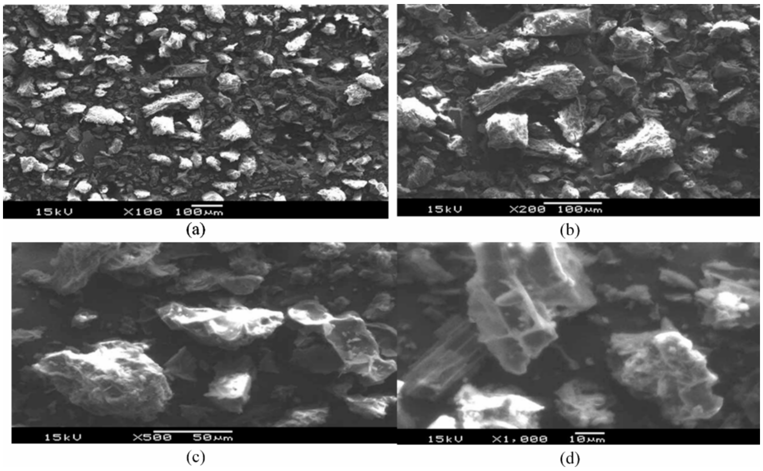

Fig. 7. Electron images of modified Asphalt: (**a**) 100 X; (**b**) 200 X; (**c**) 500 X; (**d**) 1000 X;

Elements	Mass %	Error %
Carbon C	87.42	0.14
Oxygen (O)	7.92	1.09
Silicon (Si)	0.20	0.25
Sulfur (S)	3.85	0.34
Calcium (Ca)	0.08	0.2
Aluminium (Al)	0.13	0.30
Magnesium (Mg)	0.39	0.14
Total	100.00	2.46

Table 3. ZAF fitting coefficient 0.5473.

The vibration types include stretching (ν) and bending (δ) modes, with further distinctions between equivalent (e) and inequivalent (i) stretching for C-H bonds and equal bending vibration (δ) and unequal bending (δas) for C-CH3 and C-CH2 groups. The functional groups listed are alkenes, aryl ketones, aromatic structures, CH3, CH2, and aliphatic compounds. The corresponding frequencies are provided in wavenumbers (cm2), ranging from approximately 721 to 3050 cm2.

In line with what we saw earlier about the formation of Pt. organic complexes, the FTIR spectra show specific peaks that are linked to functional groups in both the asphalt and Pt. Strong peaks in the 2851–2921 cm-1 region indicate C-H stretching in aliphatic, while the 1660 cm-1 suggests C-C stretching in aromatics. Additionally, asymmetric deformation vibrations in CH2 and CH3 are observed at 1457 cm1, and symmetric C-H deformation vibrations in CH3 are detected at 1376 cm1. The FTIR spectrum of the Pt modified asphalt binder displayed a notable crowning at 1031 cm-1 recognised to (CH3) and small peaks between 650 and 910 cm-1, characteristic of C-H vibrations in a benzene ring. The evaluation revealed no significant alterations in the modified binder's spectrum compared to the base asphalt, except for a minor peak at 721 cm1, which may indicate the presence of C-H bonds. The current study utilised the carbonyl index, an established ageing indicator, to assess the degree of oxidation during the RTFO ageing process. We observed an increase in the carbonyl index post-oxidation,

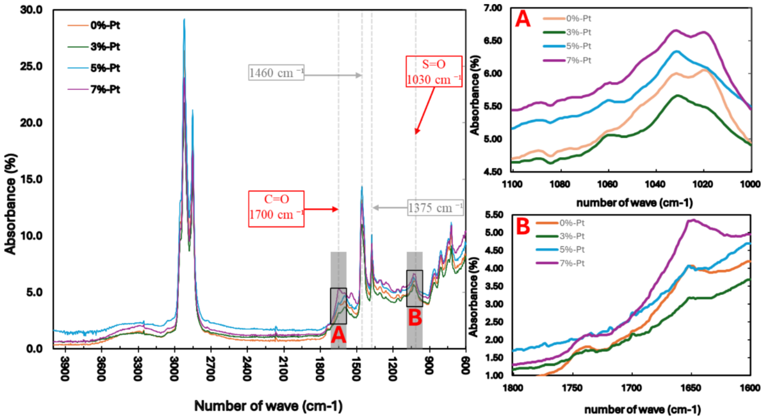

Fig. 8. FTIR spectra of base asphalt and Pt.M.A.

Relative intensity	Vibration	Group	Frequency (cm^{-1})
vw	ν C-H	Alkenes	~ 3050
vs.	e_s C-H	CH_3	2960
vs.	e_sC-H	CH_2	2920
vs.	i_sC-H	CH_2	2850
w	νC=O	Aryl ketone	1700
w	νC=C	Aromatic	~ 1660
s	δ_{as}C-CH_2	CH_3, CH_2	1458
m	δ_sC-CH_3	CH_3	1377
w	ν_sC-O-C	aliphatic	1021–1041
w	δ C-H	aliphatic	721–861

Table 4. Frequency and functional groups[82]. vs., very strong; s, strong; m, moderate; w, weak; vw, very weak; δ; equal bending vibration; δ_{as}, unequal bending; e_s, equivalent stretching; i_s, inequivalent stretching.

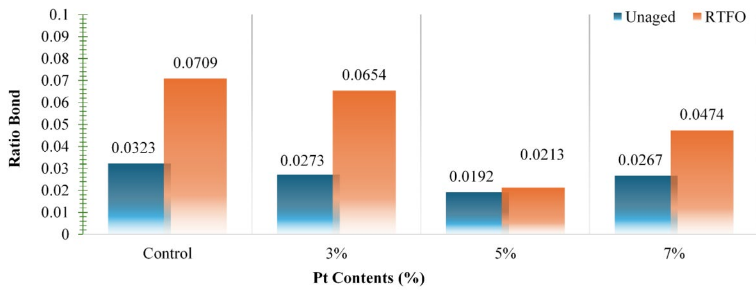

Fig. 9. Carbonyl indexes from FTIR test.

which is consistent with prior research and reflects changes in functional groups within the asphalt binder[79,80]. The linear relationship between the absorption strength and the concentration of the functional group explains the quantitative results[81].

Contrary to expectations, the content of carboxylic after the RTFO procedure decreased[83]. Figure 9 presents the carbonyl index (1700 cm-1) of modified and unmodified asphalt binders, revealing a progressive increase in the carbonyl index of the modified binder after the RTFO process compared to the unaged state. Figure 10 displays the sulfoxide index (1030 cm-1) for both modified and unmodified asphalt binders.

Clearly both modified and unmodified asphalt binders indicate a lower sulfoxide index in unaged samples compared to Pt. modified asphalt after exposure to RTFO. Therefore, Pt. enhances resistance and delays the ageing process of unmodified asphalt, potentially counteracting the observed increase in carbonyl index. Sulfoxide and carbonyl values were the lowest at 5% Pt action compared to other modifiers percentages of coupling action. In this case, the carbonyl content showed a lower value of change due to moisture preventing the temperature-persuaded thermo-oxidative to modified asphalt. Shah, V., & Scott's study addresses the economic

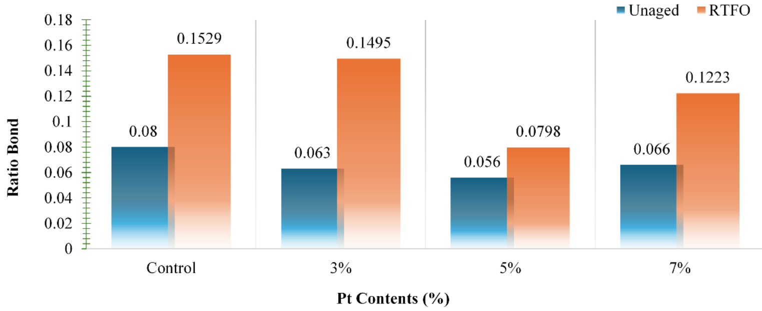

Fig. 10. Sulfoxide Indexes from FTIR Test.

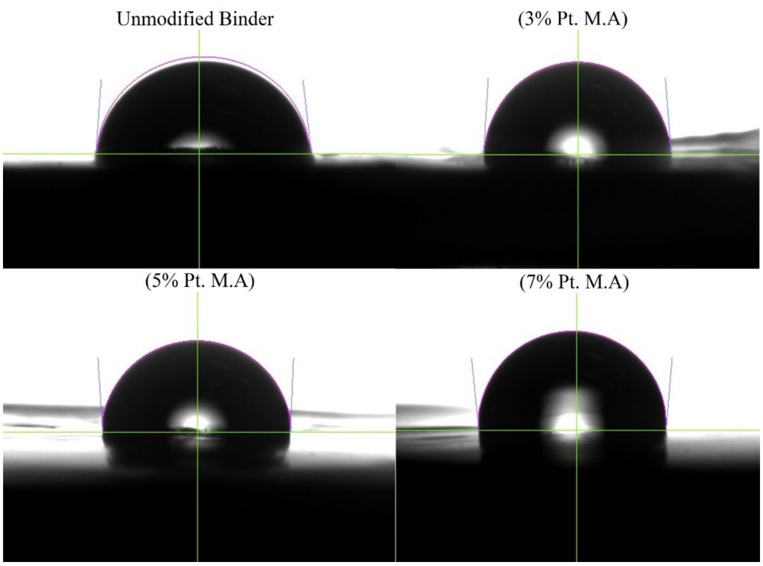

Fig. 11. Connecting angle the surface of Pt.M.A.

and environmental elements of the binder system. Upon hydration, the clay mixtures containing carbonate additions clearly generated phases similar to hydrotalcite[84]. According to Peyne's research, J found a Ca2 + release phenomenon and a polycondensation reaction happening at the same time in products made from calcined brick clay. This was shown by an FTIR analysis. Depending on the used silicate solution, this phenomenon varies in nature. The spectrum of MK metakaolin revealed the absence of the kaolinite OH stretching bands. The primary band at 1034 cm – 1 is ascribed to the stretching vibration of Si-O, while the bands at 785 and 691 cm – 1 are a result of the quartz doublets[85]. The most used functional groups were carbonyl and sulfoxide groups, which had an obvious increase due to the oxidation effect during the ageing process[81].

Moreover, Abdelrahman, M., and Katti demonstrated that the observed alterations in Si-O vibrations indicate both deformation in Si-O tetrahedra and enhanced interactions between asphalt and NC[86]. Wang, S., realised that FTIR spectroscopy is capable of monitoring polymerisation reactions and assessing the asymmetric stretching vibration of Si-O-Al links through the measurement of band absorbance within the range of 1300–900 cm^{-1} The stretching vibration of absorbed H2O was responsible for the presence of other significant bands at around 3,450 cm^{-1}, while the bending vibration of absorbed H2O was responsible for bands at roughly 1650 cm – 1[87]. Athira V. (2024) looked at how getting older changes the fatigue properties of several asphalt binders. They found a link between the binder and active filler materials in FTIR spectra at around 1700 cm-1. Additionally, the utilisation of lime resulted in a reduced rate of deterioration in the near term and enhanced resistance to long-term ageing in soft binders[88].

Surface free energy

SFE was employed to assess the moistness susceptibility according to Wilhelmy Plate. We prepared peat-modified asphalt samples using a blender. Illustrated in Fig. 11, SFE values of both unmodified asphalt binder and Pt. modified. The results indicate that unmodified binders generally exhibit higher SFE compared to modified binders. Thereby, the extent of SFE alteration varies depending on the type and percentage of modifiers used. Figure 11 presented the SFE values of modified and unmodified asphalt binders, indicating lower SFE in modified binders. Further analysis, shown in Fig. 12, reveals that the amount of modifier in Pt.M.A. directly influences SFE values, with Pt.M.A. 7 exhibiting the lower and unmodified binder the highest. The presence

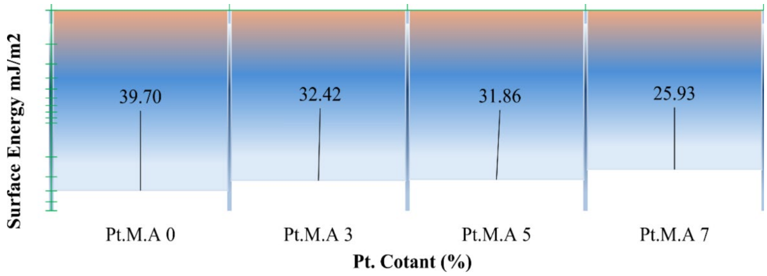

Fig. 12. Unaged modified asphalt.

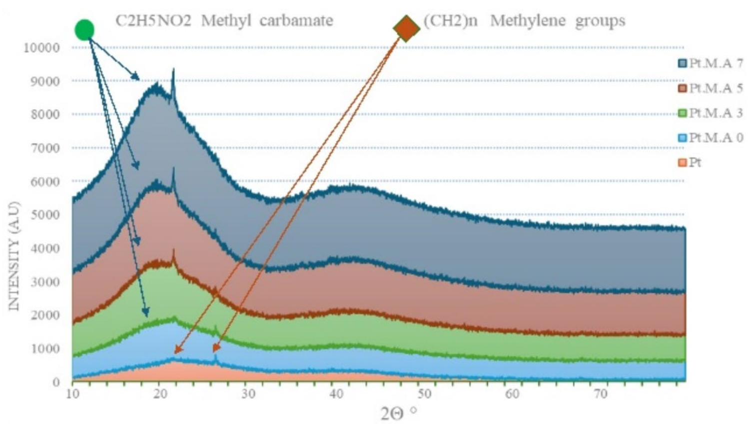

Fig. 13. Unmodified asphalt and Pt. Modified asphalt.

of amine-containing modifiers, known to enhance adhesion between acidic components, may account for the elevated SFE values observed in modified asphalt binders. Literature suggests that the amine cluster interacts with the Pt. Modifier outer layer coating; subsequently, the hydrocarbon chain interacts with the asphalt binder, contributing to increased SFE.

The presence of a long hydrocarbon chain in the amine-containing modifier may facilitate a strong bond owing to interactions in hydrophilic modifiers and hydrophobic surfaces[89]. The aforementioned factors may enhance the adhesion in the same way, leading to increased resistance to damage in most cases. Similarly, previous studies have indicated that the incorporation of carbon fibre and clay can also improve the damage resistance of asphalt binder[90].

Previous research has indicated that incorporating various modifiers into asphalt mixtures can improve their performance. Specifically, hydrated lime has demonstrated good anti-stripping properties, while in this study, asphalt modified with 5% Pt has shown notable enhancements. Furthermore, this method has been operated to assess damage resistance, revealing that the addition of clay particles can increase the total SFE of asphalt mixtures[91]. The current study, employing the SFE method, supports these findings by demonstrating that modified asphalt bindings exhibit significantly improved properties compared to base bindings.

X-ray diffraction (XRD)

An X-ray diffractometer (XRD) was used to examine the crystal and microstructure of base asphalt binder, Pt., and Pt. modified asphalt binder with varying peat concentrations. So, the XRD pattern of pure asphalt binder in Fig. 13 shows an amorphous macromolecular structure that is mostly between 10o and 30ϱ. X-ray diffraction analysis of the modified asphalt binder identified γ and graphene phases, as evidenced by peaks at approximately $2\theta = 20^{o}$. The material displays a combination of crystalline and amorphous structures. The presence of an amorphous phase is indicated by a lower intensity peak around $2\theta = 40^{o}$. All modified samples exhibit decreased peak intensities compared to the pure asphalt binder. The additives in the asphalt binder's macromolecular structure are responsible for this X-ray absorption.

This technique allowed for evaluation and investigation of the morphological features and interactions at the at the molecular level and reactions in the modified asphalt between chemically characterising morphology. The crystalline properties of asphalt materials, including layer diameter, interlamellar distance, lamellar count, and unit cell height, are analysed through XRD microstructure analysis[92]. Pt. modifier exhibited a semi-crystalline structure, characterised by medium peaks around 10° and 45°. Conversely, the unmodified asphalt binder clearly showed an amorphous structure with no distinct peaks. Pt. Asphalt modified 3%, 5%, and 7%, resulting in a new broad reflection cantered around 23°, indicating a semi-crystalline phase. The quantification of changes in modified asphalt binders demonstrated a non-linear relationship between Pt concentration and the resulting crystalline phase percentage. An initial increase with the highest Pt. concentrations, peaking at 5% Pt., followed by a subsequent decrease at 7% Pt, is observed in Fig. 13. Nevertheless, optimal Pt. concentration is needed for achieving maximum crystallinity within the modified asphalt binder.

In addition, the intensity was about 700 at $2\theta = 20^{\circ}$ for pure asphalt binder, while for PC, C, and CS, it was 650, 540, and 440, respectively. However, the peak corresponding to the amorphous structure at around $2\theta = 40^{\circ}$ did not change considerably, indicating the interaction between the main macromolecular groups and the additives in asphalt binder, which results in a uniform distribution within the modified asphalt binder samples. On the other hand, although the SEM images of all the samples showed a uniform distribution of additives, the XRD patterns of the C and CS samples showed a higher degree of uniformity and homogeneity than the others.

A new broad reflection at low angle cantered around 23 with a corresponding d spec parameter of 0.4 nm indicates a semi-crystalline phase of the Pt-modified asphalt binder. Using dedicated software, we quantified the changes in the modified blends by identifying the percentage of the crystalline phase. Thus, we found that increasing the concentration of Pt increases the percentage of the crystalline phase: at 3% Pt, it was 2.72%, and at 5% Pt, it reached its highest value of 4.75%. Conversely, the phase shows a decrease at 7% Pt. In the same way, Boussemghoune, M., discovered that the XRD diffract gram revealed the presence of anorthite and gehlenite as the primary mineral phases for ethylene glycol, gelatine, and mythical for polyethylene glycol[93]. Moreover, Terzić, A., and Pezo, L. Assessed Sportive Clays exhibit pozzolanic properties, meaning they do not hinder the cement hydration process[74]. Additionally, X-ray diffraction analyses of zeolites, both in powder and pellet forms, validate the migration of clay cations to zeolite extra framework sites. Jasra, R. V. conducted a study where both macro clay and modified Nano clay were analysed using the XRD technique[73].

Conclusion

The research examined the chemical characteristics of peat microparticles (Pt.) modified asphalt (Pt.M.A.) utilising FTIR, SEM, SFE, and XRD methodologies. The results showed that the application of Pt. as an impulse performance modifier was effective. Moreover, it improved the compatibility, adhesion, and ageing resistance of the asphalt. The FTIR examination demonstrated a thorough presence of functional groups in both the unmodified and Pt.M.A. asphalt matrices, showing enhanced compatibility due to the well-dispersed dispersion of Pt. Modified bindings demonstrated elevated surface energy relative to unmodified bindings, resulting in enhanced adhesion properties. The platinum modifier has a semi-crystalline configuration, while the base asphalt binder has an amorphous structure. The modified asphalt binder exhibits a new semi-crystalline phase, signifying a transformation in the structural composition of the binder. Nonetheless, Pt. showed exceptional performance in enhancing the characteristics of asphalt binders. This was achieved by improving the compatibility, adhesion, and durability of asphalt binders against ageing processes.

Further research work

1. The following recommendation briefly describes the area in which further research work is valuable:
2. Blend of several different types with the same base asphalt binder and other sources of asphalt binder.
3. Investigation in application of adhesion among the peat particles with asphalt binder and asphalt mixtures is required.
4. For a deeper understanding of the ageing of asphalt binder, a long-term study predicting the age of road pavement is necessary.
5. A study should also be conducted on rutting and fatigue effects for asphalt binder and mixture.
6. The wet method to produce several concentrations of modified asphalt binder was used in this study, so the dry process might be needed to investigate to evaluate the different modification methods.

Data availability

For data inquiries, please contact Ahmed Suliman Bader Ali (A.S.B.A).

Received: 30 July 2024; Accepted: 28 October 2024
Published online: 06 November 2024

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Acknowledgements
The author extends sincere gratitude to Belal Shaban for their invaluable assistance in conducting surveys, which greatly enhanced this study.

Author contributions
Conceptualization, Project Administration, Supervision, Methodology, Funding Acquisition: A.S.B.A., H.F.I., M.K.; Software, Resources: A.M.B., E.S.; Data Curation, Formal Analysis, Validation: A.M.A.A., S.I.A.A.; Writing – original draft, Writing – review and editing: S.I.A.A., A.S.B.A., H.F.I., M.K. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Ethics approval
Informed consent was obtained from all participants and/or their legal guardians.

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