Investigation of using Coal Waste in asphalt mixtures and it's effects on moisture damage with the approach of bitumen chemistry and asphalt mixture mechanical test

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ABSTRACT

Moisture damage is one of the main causes of many failures affecting the performance and durability of asphalt mixtures. This damage occurs with the entry of moisture (water) into the pavement layer and it intensifies other failures such as rutting and raveling in the asphalt mixture layers. Based on this, in this research, the impact of using different types of coal wastes (CW) as waste of its extraction process (Coal Jig and Coal Flotation Waste) on the performance of asphalt mixture, that's in facing the phenomenon of moisture damage has been investigated. After performing tests to identify the physical and chemical structure of CW, four different combinations of laboratory asphalt mixtures containing of CW were prepared. Coal Wastes in equal percentages were added to bitumen and surface free energy (SFE) and Fourier-transform infrared spectroscopy (FTIR) tests were performed on bitumen and the Indirect Tensile Strength (ITS) test was conducted on modified asphalt mixtures. The results of this study indicated that the use of Coal Jig Waste (CJW) compared to Coal Flotation Waste (CFW) increases the polar components of bitumen and increases adhesion as well. Also, the results obtained from the indirect tensile strength test indicated an improvement of resistance to moisture damage as a result of the using of Coal Jig Waste.

KEYWORDS

Hot mix Asphalt (HMA), Moisture Damage, Surface Free Energy (SFE), Coal Waste, Fourier-Transform Infrared Spectroscopy (FTIR).

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Introduction

The reduction of natural resources, increasing construction and road construction activities, and the discussion of saving energy consumption, have caused the use of waste materials in constructing concrete and pavements to become an important issue in recent years. This issue has prompted many researchers to study the possibility of using waste materials in the construction and preparation of pavement. The use of mineral resources and natural waste materials as a substitute for polymer additives is one of the solutions to reduce the negative effects of asphalt mixture modifiers on the environment and produce green asphalt, which today the pavement industry is trending towards [1]. Asphalt produced is always exposed to various types of damage, which damage caused by moisture is considered as one of the main damage to asphalt pavements. Moisture damage occurs due to the loss of adhesion and cohesion between bitumen and aggregate due to the presence of moisture [2]. To increase the resistance of asphalt mixtures against moisture, several approaches have been investigated and evaluated, and one of the methods to increase pavement quality and reduce maintenance costs with regard to additives and modifiers is bitumen modification. In this research, the effect of bitumen modification by adding Coal Waste to prevent moisture damage in asphalt mixtures has been investigated as a topic of discussion. Although the selected percent of coal waste in this study was not a significant amount, it can be a step towards returning to the cycle of waste consumption and preserving the environment.

Coal is one of the most abundant sources of energy production in the world with an annual production rate of 5.5 billion tons and its production volume in Iran reaches 310 million tons per year [3,4]. After the productivity of coal in various uses, about 50 to 60 percent of it is buried as waste, and with this act, the environment faces a serious environmental problem. The cost of preparing and using waste materials is very little, and on the other hand, the depot of these wastes creates many problems for the environment and the region [5], which can reduce the environmental damage by reducing its burial and use in the road industry.

Methodology

The purpose of the present research is to use Coal Waste as a bitumen modifier additive and to investigate its effect on the moisture sensitivity of asphalt mixture. In addition to the moisture susceptibility test, in this study, SFE and FTIR tests were also used to investigate moisture damage. According to Figure 1, new and old production Coal Waste available in the place were used. A total of 4 modes, i.e., old Flotation, new Flotation, old Jig, and new Jig, have been tested from wastes as an additive in bitumen modification.

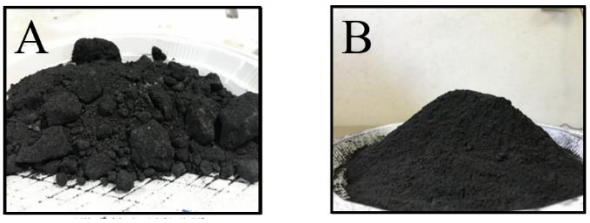

Fig. 1. Coal Wastes of used in this research: A) Jig in the form of lumps and B) Flotation passed through sieve No. 200.

Results and discussion

The results of FTIR test on the sample of control bitumen and modified bitumen with new Coal Jig and Coal Flotation Waste are shown in Table 1. The interpretation of all the wavelengths in the samples is briefly given in Table 1.

Table 1. The functional group present in bitumen samples

Wavenumber range (cm^{-1})	Functional group	Description
1030	S=O	Stretching vibration related to sulfoxide compounds
1073	C-O	Stretching vibration related to the ester group
1458	CH_3 & CH_2	Related to the aliphatic group
1600-1680	C=C	Indicating the presence of asphaltene and aromatic components
1640-1690	C=O	Stretching vibration related to the aldehyde group
1700-1720	C=O	Stretching vibration related to the carbonyl group
2850-2915	C-H	Stretching vibration related to the aliphatic group
3100-3600	O-H & N-H	Stretching vibration related to amide group and alcohol compounds

The surface free energy components of neat bitumen and bitumen containing Coal Waste additive were evaluated based on the Sessile drop method through contact angle measurement. According to Figure 2, it can be seen that the addition of Coal Flotation Waste (new and old) reduces the adhesion energy in asphalt bitumen, and Coal Jig Waste (old and new) has a positive effect on adhesion energy and increases this parameter.

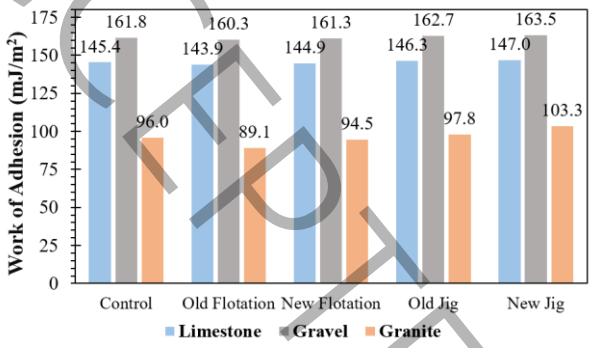

Fig. 2. Work of adhesion of modified bitumen samples with different types of aggregates

Similar to adhesion work trends, the addition of Coal Flotation Waste (new and old) increases the debonding work for granite and limestone aggregates, but there is no clear trend for gravel aggregates (Figure 2). A possible reason is that the water has a higher impact on the adhesion of asphalt binders and aggregates due to its high surface energy [1,6].

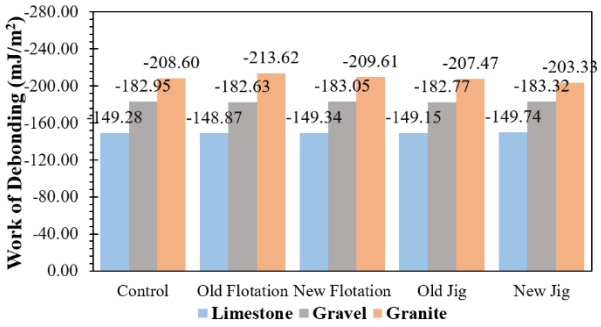

Fig. 3. Work of debonding of modified bitumen samples with different types of aggregates

The energy ratio of all asphalt bitumen samples is shown in Figure 4. By adding Coal Jig Waste (old and new), the value of the energy ratio increases for all types of aggregates, and this means that Coal Jig Waste improve moisture damage for all types of aggregates.

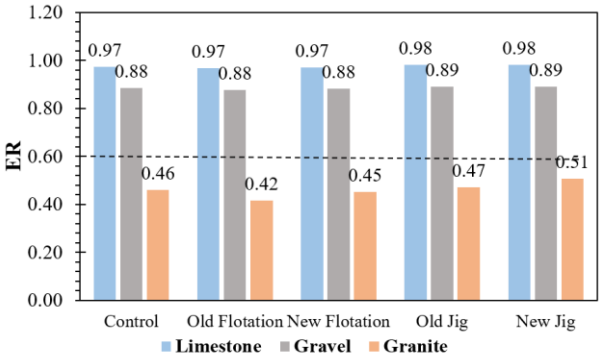

Fig. 4. Energy ratio of debonding of modified bitumen samples with different types of aggregates

The indirect tensile strength values of unconditioned and conditioned asphalt mixtures are given in Figure 5. According to the figure, it can be seen that the modified mixtures with new Coal Flotation Waste and old and new Coal Jig Waste perform better in unconditioned state.

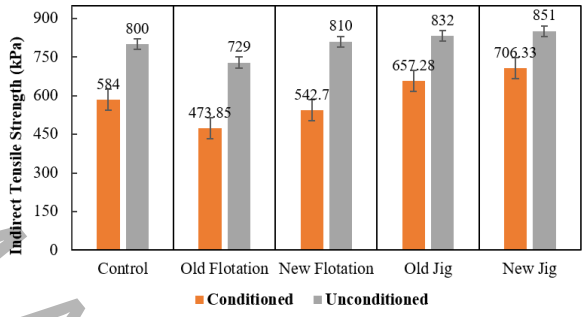

Fig. 5. The indirect tensile strength value of asphalt mixtures on conditioned and unconditioned state

According to Figure 6, only the asphalt mixture containing Coal Jig Waste had an acceptable value of TSR (79 and 83%) and it is more than the minimum standard.

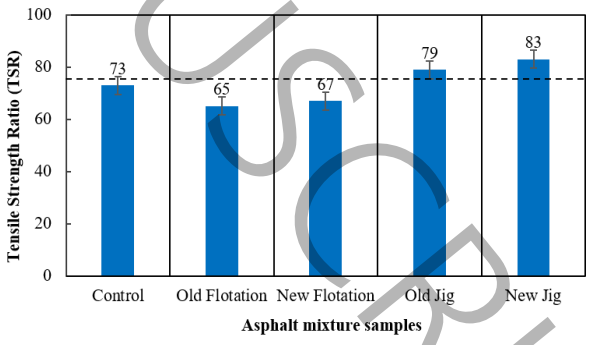

Fig. 6. The TSR value of asphalt mixtures

Conclusion

The increasing use of Coal and the production of Coal Waste in factories is a big threat to the environment, and engineers are always trying to reduce its negative effects

on the environment by using these waste materials in the production of asphalt mixtures. The main results obtained in this research include the following:

- The spectra of the Coal Jig and Coal Flotation Waste samples had the same peak with different absorbances. For example, the absorption intensity at the wavelength associated with the sulfoxide functional group (1030 cm^{-1}) in the Jig modified sample is lower than of Flotation.
- The old and new Coal Jig Waste increased the polar component of bitumen (by 4 and 24%, respectively). This increase in the polar properties of bitumen increases its adhesion to polar materials such as aggregate and water.
- Adding Coal Flotation Waste (new and old) reduces the adhesion energy in asphalt bitumen, and Coal Jig Waste (old and new) has a positive effect on adhesion energy and increases this parameter.
- Adding Coal Jig and Coal Flotation (new and old) to the neat bitumen will significantly reduce and increase the work of debonding for granite and limestone aggregates, respectively.
- Coal Jig Waste (old and new) has increased the value of the energy ratio, and this means that Coal Jig Waste improve moisture damage for all types of aggregates.
- The results of the asphalt mixture moisture damage test indicate that the samples containing Coal Jig Waste (old and new), despite having the same chemical composition as the Coal Flotation Waste, reduce the moisture sensitivity of the asphalt mixtures by 8 and 14%, respectively, and this result is in line with the SFE test result.

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