Towards the Valorization of Phosphate Wastes in bituminous materials

Mustapha Amrani[1,2,*], Yassine El Haloui[3], Pouria Hajikarimi[4], Azzouz Kchikach[1,5], Rachid Hakkou[2,6] and Yassine Taha[6]

[1] *L3G Laboratory équipe de recherche « Génie civil et Géo-Ingénierie ».Univ. Cadi Ayyad (UCA).BP 549. Marrakech 40000.Morocco.*

[2] *LCME. Faculté des Sciences et Techniques. Univ. Cadi Ayyad. BP 549.Marrakech 40000. Maroc.*

[3]*Université Cadi Ayyad, UCA, FSSM LAEPT, Boulevard Prince My Abdellah, P.B. 2390, 40000 Marrakech, Maroc.*

[4] *Department of Civil Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran.*

[5] *Geology and Sustainable Mining Department, Mohammed VI Polytechnic University, Ben Guerir. Morocco.*

[6] *Materials Science and Nano-engineering Department. Mohammed VI Polytechnic University. Lot 660.Hay Moulay Rachid.43150Ben Guerir. Morocco.*

* Corresponding author: Mustapha Amrani. Email: amrani.be.2p@gmail.com

RESUME The phosphate production process generates millions of tons of wastes annually in Morocco. These mine tailings could have negative impacts that can be observed on the surrounding environment. Therefore, innovative strategies should be proposed to valorize the solid wastes. This paper investigates a new approach of phosphate waste valorization in producing asphalt mixtures which can be a cost-effective and eco-friendly solution for managing these wastes. The main goal of the presented study is to examine the feasibility of using three phosphate wastes for fabrication of bituminous materials and to discover the better waste to be added in asphalt mixtures. Many solid wastes are selected to be used as minerals fillers. it is showed that the viscous flow behavior of the asphalt binder containing phosphogypsum and fly ash wastes is substantially improved in compression of that of asphalt binder with phosphate sludge filler. In addition, it was observed that phosphogypsum waste can enhance the mechanical properties of asphalt binder as well as its performance against rutting in comparison to the others wastes.

Mots-clefs Phosphate waste, asphalt binder, rheology, dynamic shear rheometer (DSR), valorization.

I. INTRODUCTION

Bituminous mix is a composite material including bitumen, mineral aggregates, and air voids [1]. Asphalt binder is considered as the most component of asphalt concrete mixture, that provides its consistence and defines its behavior against time, temperature and loading rate as a viscoelastic material. The linear viscoelastic behavior of asphalt binder can be characterized by the dynamic shear modulus (G*) and the phase angle (δ) parameters. These mechanical properties can be

obtained by implementing some experimental tests, such as dynamic shear rheometer (DSR), at a limited range of temperatures and frequencies [2].

Over the past three decades, several investigations have been devoted to enhance asphalt binder rheological properties through the use of different commercial additives, such as SBS, crumb rubber (CR), and polyphosphoric acid (PPA) [3]. Instead of using the aforementioned commercial additives, many researchers are working on the novel applications of product-specific wastes. In the literature, several studies have been conducted on the valorization of phosphate wastes in different materials [4]. However, very limited numbers of research have been focused on using some phosphate wastes, like phosphogypsum, to improve rheological characteristics of asphalt binder. In the present study, the feasibility of using some phosphate wastes (phosphogypsum and phosphate sludge) and fly ash to improve rheological properties of an original asphalt binder, for the road pavement applications, is evaluated. For this purpose, classical rheological characterization is performed to obtain penetration, softening point, and elastic recovery for the selected samples. Then, viscous flow, frequency sweep, and temperature sweep tests are carried out on samples using the DSR. Finally, the experimental data, including viscosity at 60°C, shear complex modulus (G*), phase angle (δ), and rutting specification parameter (G*/sin δ), of samples are compared to discover the effect of these wastes on the mechanical properties of original asphalt binder at high service temperatures.

II. Materials and test methods

The original asphalt binder has been supplied from a local asphalt company located in Morocco. In this research, three mineral fillers have been examined for improving rheological and mechanical characteristics of original asphalt binder. The first type is phosphogypsum (PG) solid waste, the second type of filler is fly ash (FA). and the last suggested waste is phosphate sludge (PS). In order to determine the basic properties of the asphalt binders, conventional test methods were performed including penetration at 25°C based on EN 1426, softening point based on EN 1427, and elastic recovery based on EN 13398 were conducted in conformity with their corresponding standards. Rheological analyses including a viscous flow behavior, frequency sweep test, and temperature sweep test were conducted by using the Discovery HR-2–TA dynamic shear rheometer with parallel plates test geometry.

III. Results and discussion

1. Classical characterization

The first part of the results represents the gradation fraction and some conventional properties of the mixtures including, penetration grade, softening point, and elastic recovery. Table 1 illustrates the granulometry analysis and Table 2 shows the classical rheological properties of the selected samples. It should be mentioned that samples are original asphalt binder (OAB), asphalt binder with 5 wt.% of PG, asphalt binder with 5 wt.% of FA, and asphalt binder with 5 wt.% of PS.

TABLE 1. **Granulometry of the used mineral fillers**

	FA	PG	PS
Grain size distribution (wt%)			
<2mm	100	100	
<200µm	92	81	100
<80µm	81	68.5	87.5
Sedimentometry analysis (wt%)			
<2µm	3	4	5
2µm to 20µm	59	13	70
20µm to 80µm	19	51.5	12.5

In comparison with the conventional properties of the OAB, the reported results in Table 2 shows that the addition of 5 wt.% PG has a considerable decrease of 7.12% in the penetration depth as well as an increase of 3°C in the softening temperature. However, the effect of the other mineral fillers was considered insignificant.

TABLE 2. Conventional properties of the selected samples

Mix	Proportion (wt.%)	Penetration (25°C; mm)	Softening point (°C)	Elastic recovery (25°C; %)
OAB	100	42	53	13
OAB:PG	100:5	39	56	14
OAB:FA	100 :5	42	53	12
OAB:PS	100 :5	43	53	11

2. Zero Shear Viscosity and Frequency Sweep Test

The second part of the results concerns the viscous flow curves (Figure 1a) as well as the frequency sweep tests (Figure 1b) by using the dynamic shear rheometer (DSR). Figure 1a depicts the variation of viscosity ($\eta_{60°C}$) according to the shear rate (γ). It can be noticed that flow curves of the four samples show a Newtonian region. The PG sample showed the highest values of $\eta_{60°C}$ in comparison with the other samples. Furthermore, the viscosity values of PG and FA samples are highly similar as well as those of OAB and PS samples. Figure 1b indicates that the phase angles of samples were observed to be close at the frequency of 0.1Hz and become wider as the frequency increased, although the shear complex modulus seemed to conserve the differentials among the asphalt binders for the entire frequency range. This can be explained by the fact that the phase angle is more sensitive to speed rates than the shear modulus. In addition, it can be inferred that the shear complex modulus of PG sample is greater than that of the other samples for a temperature of 30°C.

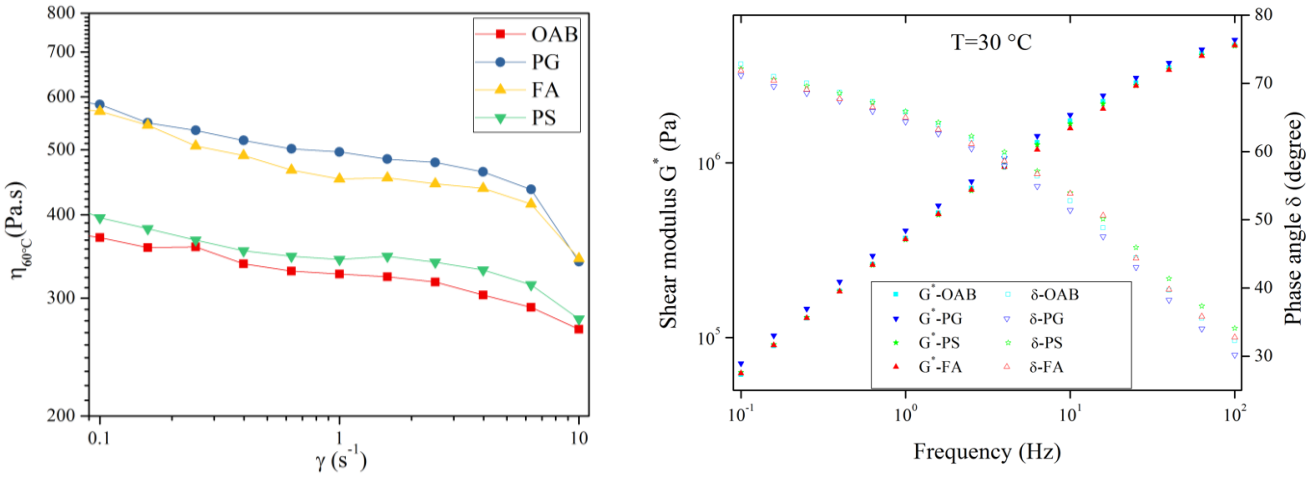

FIGURE 1. (a) Zero shear viscosity results, (b) Shear modulus and phase angle as a function of frequency.

IV. Conclusion

Experimental investigations on the potential valorization of solid phosphogypsum, phosphate sludge, and fly ash wastes, for pavement applications, has been evaluated.. The main detailed conclusions of the presented study are summarized as follows:

- The addition of 5wt.% of PG waste improved high temperature service properties of asphalt binder in comparison with the other samples. The complex shear modulus of PG sample is greater than that of the other samples at all test temperatures.
- The zero-shear viscosity of all samples fabricated with waste mineral fillers are greater than the original asphalt binder which shows the effect of these additives (wastes) on improving the viscosity behavior of asphalt binder at high temperatures in terms of rutting resistance.

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