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Laboratory Investigation on Rheological Characteristics of Asphalt Mastic with Waste Powder Materials from Mosic Tiles as Sustainable Filler

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ABSTRACT

To evaluate the possibility of using Waste Powder Material (WPM) produced from moisc tiles polishing as a sustainable filler in asphalt mixture, some properties of asphalt mastic containing WPM were investigated in this paper, and the results of the current study were compared with the common Lime Stone Mineral (LSM) filler. The investigated mastic consisted of asphalt and filler with a mass ratio of 1:1. The rheological properties were tested using the penetration, softening point, ductility, elastic recovery, furol viscosity, extensional viscosity, dynamic shear rheometer, temperature susceptibility, compatibility, and cone penetration tests. Results indicate that there is a possibility of using WPM as a sustainable filler derived from mosaic tile polishing facilities to improve the performance of asphalt. The using of WPM showed a better effect on improving the shear, rutting and fatigue resistance, as well as temperature sensitivity of asphalt mastic than the using of LSM.

Keywords:

Rheological characteristics; Waste powder materials; Lime stone filler.

1. INTRODUCTION

The continuous development in economy and industry increases the amount of waste materials, which causes rising in the global population. Any type of disposal strategy directly affects the delicate balance of the physical, chemical, and biological environments that make up our planet's biosphere [1]. For a variety of reasons, the use of waste materials in construction as a partial or full substitute for virgin materials has increased (including economics). In general, it has been discovered that the use of some waste materials, such as fiber, polyethylene, sulfur waste, crumb rubber, reclaimed asphalt pavement, recycled waste lime, polypropylene, recycled red brick powder, residual volcanic ash, carbon black, fly ash, and charcoal, is cost-efficient, responsible for the environment, and effective in enhancing some of the performance aspects of asphalt mixes [2, 3]. Studies [4-6] about using plastic in roads have discovered appreciable enhancements in the tensile strength, resistance to moisture, resistance to cracking, and durability of asphalt binder and mixtures.

When activated charcoal is used as an inorganic mastic filler with asphalt [7], concluded that it performs better than lime stone mineral filler in terms of temperature sensitivity and shear strength. Furthermore, activated charcoal has a favorable effect on the asphalt mastic's high-temperature qualities while having a mixed effect on its low-temperature aspects. The obtained results further demonstrate that physical adsorption between the charcoal as mastic filler and asphalt cement is the primary mode of interaction.

Millions tons of WPM are produced annually by Iraqi mosaic tile manufacturing companies and thrown in landfills. These accumulated wastes can provide good strength, improved abrasion resistance, resistance to rot, mildew, and many substances that might cause degradation. These wastes are excellent choices for a range of civil engineering uses, including the creation and maintenance of pavement [2].

Various firms in Iraq are producing a lot of WPM, which considered a noticeable challenge for waste management and polluting the environment [8]. Reusing the WPM is the most environmentally beneficial way to get rid of bulk rubbish. The considerable use of composite materials in Iraq for the construction and upkeep of road surfaces creates a sizable opportunity for recycling of WPM. The safe disposal of bulk waste is important, but it's also important to minimize the negative environmental effects that the use of fillers in paving construction industry has on the environment [9].

The greatest way to lower those energy and emission levels is to increase ongoing efforts to lessen the quantity of filler required. This can be done mostly by lowering or eliminating the amount of popular fillers in asphalt mixtures, such as calcium carbonate, and by increasing the lifespan of asphalt mixtures [9].

Like most of the solid waste put in landfills, WPM does not decompose. Approximately 10 to 20 million tons of WPM are reportedly generated and dumped in Iraq per year. WPM costs landfills about $105 for each ton. As a result, the cost of landfilled areas varies annually, from 665 to 2000 000 USD [8]. In order to cut costs and environmental damage, WPM is projected to become a preferred mineral filler for asphalt. WPM is an attractive choice that also seems to improve the qualities of paving concrete mixtures [2] since it is more economical (0.25 USD/kg) comparing to other fillers, such as calcium carbonate.

Only a few studies [2, 9, 10] were conducted during the past 10 years on the use of some of these wastes as a filler or polymer fiber in bitumen mixtures. The outcomes from incorporating garbage in asphalt mixtures are significant and encouraging, according to these investigations. On the other hand, no research has been carried out on the use of WPM as a filler in asphalt paving mixtures. When replacing or adding any waste materials to bitumen mixtures, three key considerations should be made [11]: first, the annual cost evaluations should be carried out to ascertain each material's efficacy, second the impact of the asphalt on the caliber and effectiveness of the pavement, third the incorporation of garbage, which significantly raises the price of the pavement while also reducing its useful life or raising the cost of maintenance would be poor economics. Utilizing waste materials also considers beneficial to the environment of their disposal in landfills.

The huge potential for WPM recovery and encapsulation is demonstrated by these data. Bituminous road surfaces are a fantastic method to add a lot of distinctive WPM to a pavement design whilst also enhancing the durability and strength of the pavement courses. The new research is anticipated to help improve our knowledge on how paving mixes including WPM perform for the long-duration construction of roads. To the best of authors' knowledge, there is no research has been done on employing WPM as a mineral filler in asphalt mixtures. There is still a need for more research on this subject, thus that is what has been done.

2. OBJECTIVES OF THE RESEARCH

The major goal of the current experimental study was to examine the qualities of WPM and asphalt mastic that contain WPM in relation to one another.

Many tests including penetration, softening point, ductility, elastic recovery, furol viscosity, extensional viscosity, dynamic shear rheometer, temperature susceptibility, compatibility, and cone penetration were applied to evaluate the related properties of asphalt mastic with WPM and the feasibility of using WPM as a sustainable filler in asphalt pavement compared with conventional lime stone filler (LSF).

3. TESTS PROCEDURES

3.1. Base asphalt, WPM and LSM

Asphalt, which utilized in this research was 40-50 (A40) penetration grade and its physicochemical characteristics were tabulated in Table 1. The results indicated that A40 satisfy ASTM [12] and SCRB [13] specifications for penetration graded asphalt.

Table 1: Properties of base asphalt

Characteristics	Value	SCRB [13]	ASTM [12]
Penetration (25°C,100g,5s, dmm	44	40-50	40-50
Softening point, °C	51.3	-	50-58
Ductility((25°C, 5 cm/min, cm)	150^+	>100	>100
Elastic recovery (25 °C, 50 mm/min, cm),%	65	-	-
Flash point (COC, °C)	277	>232	>240
Loss on heat (5hrs, 163 °C, %)	0.12	0.75 max.	0.2 max
P.I.	-1.668	-	-2 to +2

Retained Penetration % of original (25 °C,100gm,5 s,0.1mm)	61	55 min.	-
Residue Ductility (25 °C, 50 mm/min, cm)	55	75min.	-

Waste powder materials (WPM) are chosen as filler for the asphalt mixture. WPM, which is a byproduct of mosaic tile polishing factories, is piling up in Nineveh province, Iraq. WPM is collected and dried to a constant weight in a 105 °C oven, and then fragmented by a jaw crusher to achieve the same percentage passing as LSM. In Table 2, the physico-chemical and gradational characteristics of WPM materials are displayed.

Table 2: Physicochemical properties of LSM and WPM

Test property	Value (wt. %)		
	LSM	WPM	
Silicon Dioxide (SiO_2)	22.23	22.19	
Aluminum Oxide (Al_2O_3)	6.18	3.95	
Ferric Oxide (Fe_2O_3)	3.27	0.205	
Calcium Oxide (CaO)	61.3	66.67	
Magnesium Oxide (MgO)	3.9	0.68	
Potassium Oxide (K_2O)	0.16	0.42	
Sulfur Trioxide (SO_3)	2.13	2.73	
Sodium Oxide (Na_2O)	---	0.064	
Specific gravity	2.734	2.808	
Gradation			
Sieve size (mm)	Passing (%)		NCCL [14]
	$CaCO_3$	WPM	
0.6	100	100	100
0.3	100	100	95-100
0.075	98	94	70-100
Plasticity index	1.2	2	Max. 4%

3.2. Asphalt mastic production

For the production of asphalt mastic, each of WPM and LSM were mixed with A40 at a mass ratio of 1:1 under (155±5°C, 500 rpm, and 3±1 minutes) conditions to obtain a homogeneous mastic.

3.3. Testing rheological and mechanical characteristics of WMA binders

The rheological and mechanical tests conducted on WPM and LSM mastics as per ASTM [14]. These testes are included penetration (D-5), softening point (D-36), ductility (D-113), elastic recovery (D-3633M), furol viscosity (D-88), extensional viscosity, dynamic shear Rheometer (D-7175), temperature susceptibility, compatibility, and cone penetration.

4. RESULTS AND DISCUSSIONS

4.1. Penetration and softening point

Penetration and softening point of WPM and LSM mastics were examined, and the results are depicted in Figures 1 and 2. The results show that the using of WPM positively improved the A40 characteristics. For the penetration test at 25°C, the asphalt mastic with WPM has 40 dmm and the asphalt mastic with LSM has 42 dmm. From these results, it can be notified that the asphalt mastic with WPM behaves well against shear resistance in moderate to high temperatures than the asphalt mastic with LSM. As compared with A40, the reduction in the penetration of the asphalt mastic with WPM and the asphalt mastic with LSM at 25°C were 9.0%, and 4.6%, respectively. When it comes to penetration, the averages of the WPM and LSM mastics (i.e., they all show approximately similar penetration) were significant.

The softening point, R&B traditional test was utilized to examine the high-temperature rutting characteristics of WPM and LSM mastics. From Figure 2, R&B for WPM and LSM were noticed to be 61 and 57°C, respectively. It is shown that WPM mastic exhibited R&B higher than LSM. WPM and LSM exhibited 19% and 11.2% higher R&B than A40 (i.e., WPM more resistance against rutting than LSM). This is because that WPM contains higher amount of Calcium Oxide (CaO) in its chemical composition than LSM.

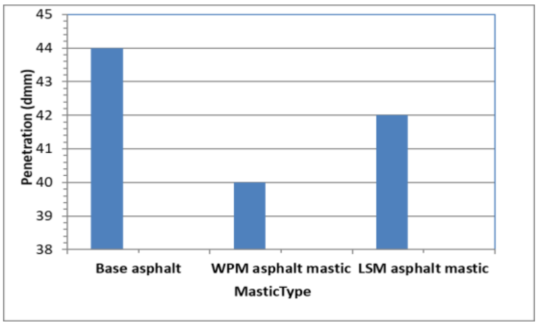

Fig. 1 Penetration of asphalt mastic

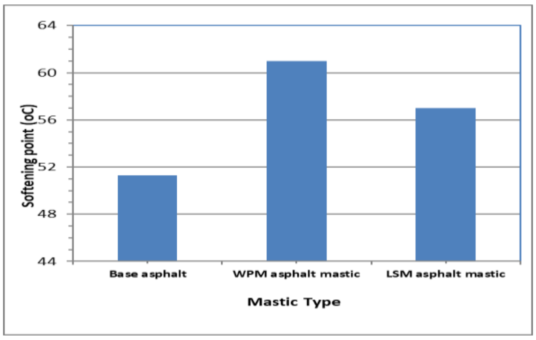

Fig. 2 Softening point of asphalt mastic

4.2. Ductility and elastic recovery

The ductility (Du) and elastic recovery (Er) test was performed to examine the elasticity characteristics of WPM and LSM mastics. Figure 3 shows the results of Du test at 25°C for WPM and LSM mastics. . The Du values are 95 and 101 cm at 25°C for asphalt mastics with WPM and LSM, respectively. Figure 3 shows that the ductility of asphalt mastic with WPM slightly lower than the ductility of the asphalt mastic with LSM and at the same time lower than the minimum limit of ASTM [12] and SCRB [13] requirements of 100^{+}cm. This is because that the LSM is finer than the WPM as indicating in Table 3. However, WPM mastic provides adequate adhesive property and thus adequate behavior in the field.

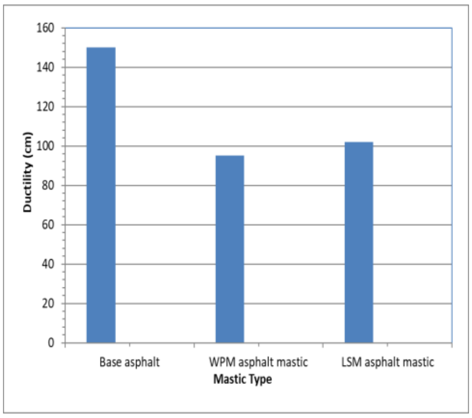

Fig. 3 Ductility of asphalt mastic

Similarly, Er percentage at 25°C for WPM and LSM mastics were found to be 79.6% and 82%, respectively. Testing Figure 4, it can be notified that no significant in Er values at 25°C. These results notify that WPM and LSM have the same elasticity value at medium temperatures (i.e., WPM and LSM give similar tensile strain of asphalt-mix layer in flexible pavement).

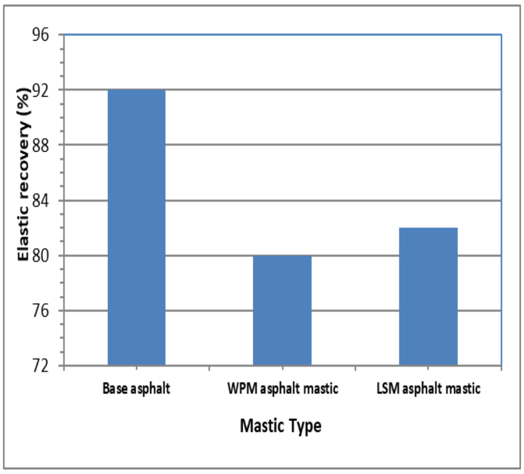

Fig. 4 Elastic recovery of asphalt mastic

4.3. Furol viscosity

To determine the mixing and compaction temperatures of WPM and LSM mastics, the furol viscosity (FV) of the two materials was measured using a Saybolt-Furol viscometer at various temperatures. According to the Asphalt Institute manual, these temperatures result in Saybolt-Furol viscosities of 85 and 140 s, respectively. Figure 5 depicts the FV. It was notified that WPM and LSM having mixing temperatures values of 163 and 162°C, respectively. Similarly, the compaction temperatures for these mastics were found to be 156 and 155°C, respectively. From these, it can be concluded that the viscosity of WPM binder is similar to that of LSM.

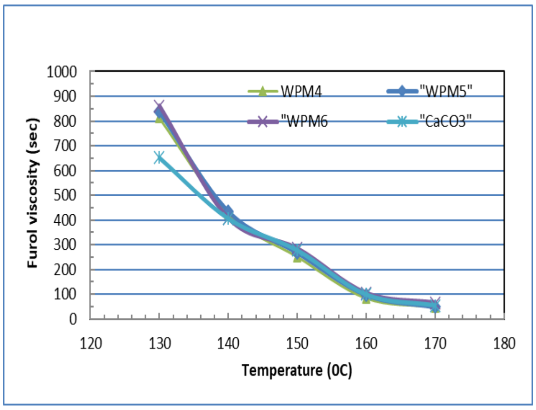

Fig. 5 Furol viscosity of asphalt mastic

4.4. Dynamic Shear Rheometer test (DSR)

The main technique for figuring out a material's viscoelasticity is rheological measurement. The dynamic shear rheometer (DSR) test was used in this study to determine the asphalt binder's shear modulus and phase angle. The rheological characteristics and rutting resistance of asphalt mastic were assessed at 76°C in accordance with ASTM D7175 [15]. An asphalt film sample with dimensions of 25 mm in diameter and 2 mm in thickness was sandwiched in this experiment between a fixed steel plate and an oscillating plate with a 10 rad/s angular frequency while being subjected to a constant torque. The rutting ($G^*/\sin\delta$) and fatigue ($G^*\sin\delta$) resistance parameters were determined as shown in Figures 6 and 7. These figures indicate that WPM asphalt mastic is more resistance to rutting ((i.e., smaller amount of deformation of asphalt materials or shorter loading time) and fatigue at high temperatures than LSM asphalt mastic, meaning that WPM asphalt mastic has better high temperature property than LSM.

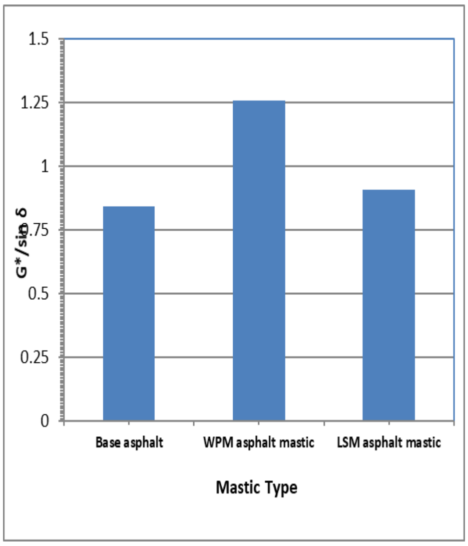

Fig. 6 Rutting parameter of asphalt mastic

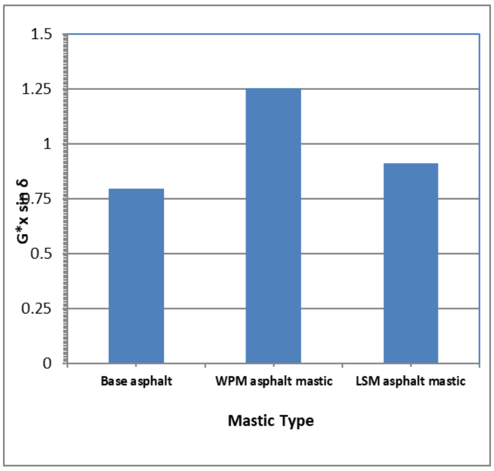

Fig. 7 Fatigue parameter of asphalt mastic

4.5. Temperature susceptibility

The penetration index (P.I.) equation (2) [16] were adopted to examine the temperature susceptibility of WPM and LSM mastics.

P.I.= [(20-500A)/ (1+50A)] **(2)**

A = [(log pen.@T-log 800)/ (T-R&B)]

Where:

T = Testing temperature

R&B= Softening degree.

Figure 8 shows between the P.I. and mastics. The P.I. values of WPM and LSM mastics are 0.714, and 0.0033, respectively. It can be noticed that both WPM and LSM mastics in the normal range of P.I. (-2.0 to +2.0). This depicts that WPM mastic is less susceptible to temperature varies than LSM.

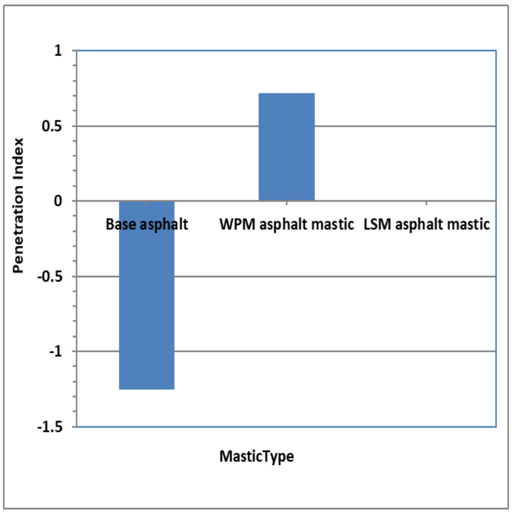

Fig. 8 Penetration index of asphalt mastic

4.6. Compatibility tests

The compatibility between WPM, LSM and A40 was examined by passing the binder at the mixing temperature of each binder through a 0.075mm US sieve. It was noticed that the WPM and LSM mastics thus prepared can be stored for future use.

4.8. Extensional viscosity

The extensional viscosity (λb) of WPM and LSM mastics in Mpa.s was calculated from equation 5 reported by Al-Hadidy et.al [16, 17].

$$\lambda_b = 3\times 10^{-6} \{ 1.3 * 10^{[3 + (R\&B - T_{binder})/10]} \} \quad (5)$$

Where:

R&B and T_{binder} (as defined above).

Table 5 shows λb of WPM and LSM mastics. It can be noticed that the λb of WPM and LSM at 25°C 15.526 and 6.181 Mpa.s, respectively. Similarly, these values at 60°C were depicted to be 4.9×10^{-3} and 1.954×10^{-3}. This depicts that increasing in temperature leads to decrease in binder λb. Furthermore, WPM has a λb value higher than LSM.

Table 3: Extensional viscosity of asphalt mastic

Asphalt mastic	λb, Mpa.S	
	25°C	60°C
A40	1.663	0.526×10^{-3}
WPM	15.526	4.909×10^{-3}
LSM	6.181	1.954×10^{-3}

4.10. Shear strength

The cone penetration assay (CPA) was introduced to assess the WPM and LSM shear strength and as shown in Figure 9. 1:1 wt. ratio of A40 binder and WPM/LSM as a filler (100 passing 0.075mm) were: (1) blended at the WPM/LSM mixing temperature; (2) WPM/LSM: filler was placed into tin vessel and the later was left in laboratory for 40±5 min and then it was cured in water at 30°C for 60 min; (3) the CPT was applied on the samples with cone weight (w) of 200±5 g until the CPA dial reading (h in dmm) became stable; and (4) the shear stress τ (kPa) of WPM/LSM: filler at the inclined cone surface with angle (α/2 = 15°) was calculated using equation 6:

$$\tau = [981\times w \times \cos^2(\alpha/2)]/[3.14\times h^{2\times} \tan(\alpha/2)] \quad (6)$$

Triplicate samples were tested for each WPM dosage and LMS. Figure 10 depicted that the shear stress of WPM and LSM are 13.48 and 12.56 kPa, respectively. It can be noticed that the shear stress of WPM is better than LSM mastic.

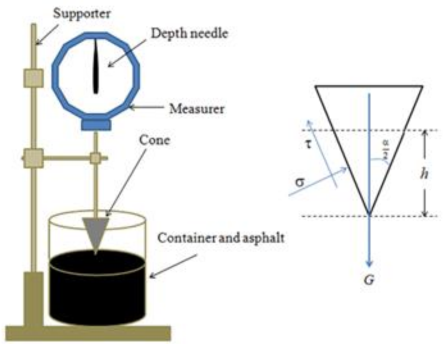

Fig. 9 Shear strength test

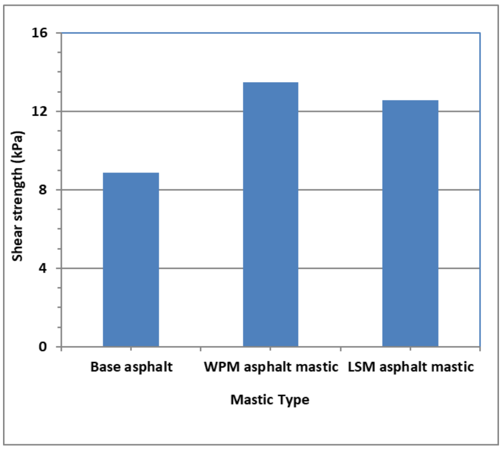

Fig. 10 Shear strength of asphalt mastic

5. CONCLUSION

This study relied on experimental tests to examine the rheological properties of asphalt mastic with waste powder materials (WPM) as a sustainable filler. One can infer the following conclusions.

1. Compared with LSM, the WPM has porous surface and approximately similar percentage passing #200 sieve, indicating the possibility and feasibility of WPM as filler obtained from the polishing of mosaic tiles to improve the performance of asphalt. In addition, the physical adsorption between the WPM filler and asphalt is the main mode of action.
2. The WPM has a greater impact than the LSM in raising the shear strength of asphalt binder. Filler in asphalt mastic can absorb and stabilize asphalt (particularly light components), as well as improve viscosity and rigidity.
3. Although WPM has a greater impact on high temperatures (G*/sin δ) and the characteristics of asphalt mastic, it greatly outperformed LMF when added.
4. WPM and LSM can effectively improve the high temperature sensitivity of asphalt binder, and WPM is the better one.
5. WPM exhibited lower penetration, ductility, and elastic recovery at 25°C, and higher softening points than LSM. Furthermore, WPM exhibited similar mixing and compaction temperatures to those for LSM.
6. The λ_b of WPM at 25°C and 60°C was found to be higher than that for LSM.

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التحري المختبري للخصائص الريولوجية للأسفلت ماستك الحاوي على مخلفات الطحن الناتجة من عملية جلي الكاشي الموزائيك كمادة مالئة

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الملخص

لتقييم امكانية استخدام مخلفات مواد الطحن من جلي الكاشي الموزائيك كمادة مالئة في المزجات الاسفلتية، بعض خصائص الأسفلت ماستك الحاوي على هذه المخلفات تم التحري عنها في هذه الدراسة، ومقارنتها مع مادة كاربونات الكالسيوم. الأسفلت ماستك المنتج احتوى على نسبة وزنية 1:1 (اسفلت: مادة مالئة). الخصائص الريولوجية تم اختبارها عن طريق النفاذية، نقطة الليونة، الأستطالة، الرجوعي، لزوجة فورل، اللزوجة الفائقة، القص الريولوجي، تأثر الحرارة، التجانس و مخروط النفاذية. أوصحت النتائج امكانية استخدام مخافات كاشي الموزائيك كمادة مالئة لتحسين كفاءة الأسفلت من حيث مقاومة القص، التشوهات الدائمية والكلل بالاضافة الى مقاومة التغيرات بالحرارة مقارنة بكاربونات الكالسيوم.

الكلمات الداله :

الخصائص الريولوجية، مخلفات مادة طحن كاشي الموزائيك، كاربونات الكالسيوم.