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EFFECT OF FILLER MATERIALS ON MARSHALL PROPERTIES AND RUTTING OF ASPHALT MIXTURES USING WHEEL TRACKING TEST: A COMPARATIVE STUDY

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Abstract

In the past decade, the road network in Jordan has been exposed to a large volume of traffic, leading to distress in the pavements and consequently the need for continuous maintenance and rehabilitation of the network. The main objective of this study was to evaluate the effect of replacing limestone dust in the asphalt mixtures by different filler materials (waste toner, waste glass, waste rubber and electric arc furnace dust) on Marshall properties and on reducing the permanent deformation. Superpave specimens were prepared to determine the permanent deformation under dry and wet conditions with a wheel tracking device. The device applies moving loads on the samples and the consequential rutting can then be determined. The results of Marshall tests showed that the use of waste toner, waste rubber and electric arc furnace dust can enhance the Marshall properties, whereas waste glass filler did not. The results also showed that the permanent deformation of specimens modified by waste toner, waste rubber and electric arc furnace dust was less than for the reference mixtures by (82.2%, 43.6%, 28.7%) and (58%, 32.5% and 14.2%) at dry and wet conditions, respectively. In contrast, specimens with waste glass filler had increased permanent deformation compared with the reference mixtures by 64% and 23% at dry and wet conditions, respectively.

Keywords: Asphalt mixtures, Filler materials, Rutting, Wheel tracking test, Moisture susceptibility.

1. Introduction

Many researchers have used filler materials to enhance the performance of asphalt or asphalt mixtures. These filler materials play a major role in improving the resistance to permanent deformation (the rutting resistance) of a paving mix, increasing the adhesion between the asphalt and the aggregate and reducing pollution of the environment (e.g., Simone et al. [1], Abdelhak et al. [2]). Rutting in a flexible pavement is shown in Fig. 1.



Fig. 1. Rutting in a flexible pavement.

The effect of waste toner on asphalt mixture performance is studies by several researchers (e.g. Notani et al. [3], Khedaywi [4], Rema et al. [5], Solaimanian et al. [6], Al-Mistarehi et al. [7], Kumar et al. [8]). Notani et al. [3] used the amplitude sweep test to find the effect of waste toner on the fatigue resistance of asphalt binders. The authors added waste toner at 4%, 8%, 12% and 16% by weight of asphalt binder and found that 12% waste toner gave the best fatigue resistance compared with other percentages. Khedaywi [4] blended asphalt binder with five contents of 0%, 5%, 10%, 15% and 20% of waste toner by volume of asphalt binder and found that when the content of waste toner was increased, the penetration and ductility would decrease while the specific gravity, viscosity, softening point, flash and fire point would increase.

Rema et al. [5] obtained a 33% increase in Marshall stability when blending 10% of waste toner with asphalt compared with their conventional mixture. Similarly, Solaimanian et al. [6] found that the stability and strength of the mixture modified with waste toner were higher than those of the unmodified mixture. They also reported that stiffness and viscosity increased as the content of waste toner increased. Kumar et al. [8] obtained a considerable increase in Marshall stability at 16% toner at 5.5% optimum binder content (OBC).

Similarly, the effect of waste glass on asphalt mixture performance is investigated by several researchers (e.g. Maybodi et al. [9], Abu Salem et al. [10], Simone et al. [1], Tremblay et al. [11], Al-Saffar [12], Jony et al. [13]). Maybodi et al. [9] studied the effect of waste crushed glass on the behavior of asphalt mixtures. Asphalt and waste glass mixtures are called glasphalt [9]. The authors replaced up to 15% of the fine aggregate with crushed glass and found that the skid resistance improved up to 20%. Abu Salem et al. [10] investigated the Marshall properties of glasphalt mixtures, replacing the fine aggregate with 0%, 5%, 10%, 15% and 20%

of crushed glass by weight of aggregate. The authors found that with crushed glass replacing 10% of the aggregate, the Marshall stability increased by 11% and the OBC was reduced by 7% compared with the unmodified mixtures. The use of glasphalt may cause stripping and raveling, so Abu Salem et al. suggested using hydrated lime to reduce these effects [10].

When Simone et al. [1] conducted experimental studies on the indirect tensile stiffness, strength and creep properties of recycled dense-graded asphalt mixtures modified with waste glass powder filler, the rutting resistance was found to be better than that of the control mixture. In contrast, Tremblay et al. [11] found that replacing 10% by weight of the aggregate with crushed glass reduced the binder content and rutting resistance but increased workability.

Al-Saffar [12] found that replacing limestone dust with crushed glass at 8% of the total weight of the aggregate increased the Marshall stability by 14.3% and reduced flow by 44.3% compared with the ordinary mixture. Jony et al. [13] showed that when 7% by weight of aggregate was replaced by glass powder, the Marshall stability was increased by 13% while flow was reduced by 39% compared with control mixture.

The effects of crumb rubber on the mechanical properties of modified asphalt mixture with nanomaterial have been studied by several. Arabani et al. [14] mixed asphalt with zycosoil at 1%, 2.5% and 4% by weight of binder, and then added crumb rubber at 1%, 3% and 5% by weight of the aggregate. They found that the accumulated strains decreased with 1% and 3% of crumb rubber, so that the mixture would be more elastic to prevent permanent deformation. The stiffness moduli of the mixtures at 1% and 3% of crumb rubber were larger than that of the control mixture, but at 5% crumb rubber, the stiffness modulus was reduced. The addition of crumb rubber reduced the indirect tensile strength unless zycosoil was added to the asphalt: in the latter case, the indirect tensile strength was higher than the control mixture at 1% and 3% crumb rubber.

Irfan et al. [15] evaluated the resilient modulus, indirect tensile strength and permanent deformation of asphalt mixtures modified with crumb rubber. When the content of crumb rubber was 8% by weight of asphalt binder, the Marshall stability increased by 30% and resilient modulus by 43% while rutting decreased by 12% compared with the control mixture. Subhy et al. [16] found that the addition of crumb rubber resulted in a reduction in permanent deformation together with an improvement in fatigue cracking at lower strains levels. Abdelhak et al. [2] studied the performance of recycled asphalt when mixed with crumb rubber and found that the resistance to rutting was improved. Ghasemi and Marnadi [17] investigated the effect of glass powder and crumb rubber on an asphalt mixture and found that the mixture had 50% and 25% higher indirect tensile strength than the control mixture and the mixture prepared with only crumb rubber respectively. Also, the Marshall stiffness of the modified mixture was twice that of the unmodified mixture.

With respect to Electric Arc Furnace Dust (EAFD), Loaiza and Colorado [18] studied the effect of EAFD with a high content of ZnO on the Marshall stability and flow of asphalt mixtures. Asphalt was blended with different percentages of EAFD to prepare the Marshall specimens. The addition of 10% or 20% of EAFD by weight of asphalt increased the stiffness of the asphalt mixture, but the mixtures didn't meet the Marshall requirements, so the authors suggested using these mixtures in noncritical structural pavements. Alsheyab and Khedaywi [19] determined that when

the percentage of EAFD is more than 15% by volume of asphalt, the highest resilient modulus occurred at 40˚C and frequencies of 4 Hz and 8 Hz.

Khedaywi and Alsheyab [20] investigated the effect of 0%, 5%, 10%, 15% and 20% EAFD by volume of asphalt on the properties of asphalt concrete using the Marshall test method. Flow increased with increasing content of EAFD, but the stability, unit weight, voids filled with asphalt and stiffness increased then decreased while air voids and the voids in mineral aggregate decreased then increased. They concluded that 5% EAFD would meet the criteria of Marshall properties. When evaluating the performance of asphalts mixed with different amounts of EAFD, the same authors found that increasing the percentage of EAFD by volume of asphalt led to decreases in the penetration and ductility and increases in the specific gravity, softening point, rotational viscosity, flash, and fire point [21].

Valentin et al. [22] evaluated the characteristics of quarry dusts and industrial by-products as potential substitutes for traditional fillers and their impact on the water susceptibility of asphalt concrete. The results indicated that substitution of blast furnace slag or recycled concrete in place of some conventional fillers produces superior properties. Also, mixing quarry dusts with Portland cement or talc was found to be beneficial in terms of rendering the originally hydrophilic dusts to become more hydrophobic.

Several studies were conducted to find rutting of asphalt mixtures using the wheel tracking test (e.g., Al- Shaybani [23], Hussan et al. [24], Al- Kafaji et al. [25], Oluwasola et al. [26], Morea et al. [27], Ahmad et al. [28], Rafiq et al. [29]). Al- Shaybani [23] modified asphalt with 1%, 3% and 5% of silica fume by weight of asphalt binder and studied the rutting performance of the resulting mixes through the wheel tracking test at 50˚C with 5000 passes of the wheels. The best rutting resistance occurred with 3% silica fume. Hussan et al. [24] developed a nonlinear regression analysis model that predicts the rutting depth based on the performance of different asphalt mixtures in the wheel tracking test. The model correlates rutting depth to testing temperature, number of passes, penetration of binder and coarse aggregate flakiness index. Al- Kafaji et al. [25] prepared a cold bitumen emulsified mixture using ordinary Portland cement. This mixture is modified by acrylic polymer with different percentages from 0% to 5% by weight of residual bitumen. Tests for permanent deformation using the wheel tracking test were performed with results showing that the best performance for permanent deformation resistance occurred with 1.25% of acrylic polymer.

Oluwasola et al. [26] investigated the effects of adding electric arc furnace steel slag and copper mine tailing on asphalt mixture performance. The asphalt pavement analyzer was used to find the rutting resistance. The specimens were prepared using a Superpave gyratory compactor with diameter of 150 mm and height of 75 mm. The tests were accomplished in the dry condition at 60˚C. The modified mixture gave a lower rut depth than the conventional mixture. Morea et al. [27] studied the permanent deformation of asphalt mixtures using the wheel tracking test, finding that rutting depth depends on binder properties, loading and temperature. Ahmad et al. [28] found the correlation between the dynamic modulus of the simple performance test at different temperatures and frequency conditions and the rut depth of mixture using the Wessex wheel tracking test. The authors concluded that the simple performance test is good for evaluating the potential for rutting.

It is clear from previous research that fillers can be added to asphalt mixtures to enhance the Marshall properties, to minimize the rutting of the pavement and enhance resistance to permanent deformation. However, a comparative study of these filler materials on Marshall properties and rutting using the wheel tracking test is absent from literature. In this research, waste toner, waste glass, waste tire rubber and electrical arc furnace dust (EAFD) were used to replace limestone dust in the aggregate. The effect of replacing limestone dust with filler materials on Marshall properties was evaluated. Rutting of the modified asphalt mixtures was evaluated by the wheel tracking test. The moisture susceptibility of the modified asphalt mixtures was found by testing each mix in the wet condition at high temperature. The main objective of this study was to evaluate the effect of replacing limestone dust in the asphalt mixtures by different filler materials on Marshall properties and on reducing the permanent deformation in order to find which filler is best used.

This study is expected to expand knowledge of the effect of replacing of limestone dust in bituminous mixtures with different filler materials on reducing the permanent deformation. Also, this study will show the effect of moisture on the permanent deformation of the modified mixtures. The results of the study will lead to improvements in the performance of hot mix asphalt (HMA), extend road service life and reduce maintenance and rehabilitation costs.

2. Materials Used

2.1. Asphalt binder

Asphalt binder is the main binding component in flexible pavements due to its excellent properties of adhesion, binding the aggregate and resistance to water. In this research, the grade of asphalt binder mainly used in Jordan, that of penetration grade (60-70) was used. The asphalt binder was obtained from the Jordanian Petroleum Refinery Company (JPRC) in Zarqa- Jordan. The physical properties of the asphalt binder are presented in Table 1.

Table 1. Physical properties of asphalt binder.

Property	Unit	Test specification	Test result	Requirements min/max
Penetration	0.1 mm	ASTM D5	60	60/70
Ductility	cm	ASTM D113	130	100+
Specific gravity	-	ASTM D70	1.01	1.01/1.02
Softening point	ºC	ASTM D36	47	45/52
Flash point	ºC	ASTM D92	310	300/330
Fire point	ºC	ASTM D92	350	300/330
Rotational Viscosity (RV)	Pa.s	ASTM D4402	0.462	0.17/0.28

2.2. Aggregate

Aggregates are defined as collective materials of sand, gravel and crushed stone. In general, aggregate is divided into coarse, fine and mineral components. Coarse aggregate is any aggregate that is retained on sieve #4. Fine aggregate is any aggregate that passes sieve #4 and is retained on sieve #200. Dust or mineral aggregate is any aggregate that passes sieve #200. In this research, limestone aggregate obtained from the Irbid quarries in the north part of Jordan was used. This aggregate was sieved then recombined in the laboratory to meet the gradation specification of the Jordanian Ministry of Public Works and Housing (MPWH)

(2010) [30]. Table 2 shows the physical properties of this aggregate. Table 3 shows the aggregate gradation used in the mix design.

Table 2. Physical properties of aggregate.

Type of limestone aggregate	Test specification	Bulk specific gravity	Apparent specific gravity	Absorption %
Coarse	ASTM C127	2.52	2.53	7.8
Fine	ASTM C128	2.48	2.50	5.1
Dust	ASTM C128	2.53	2.55	-

Table 3. Design aggregate gradation according to MPHW (2010) [30].

Sieve size	Specification limits % passing	% Passing mid-point	% Retained	Cumulative % retained
3/4" (19.5 mm)	100	100	0	0
1/2" (12.5 mm)	80-100	90	10	10
3/8" (9.5 mm)	56-80	68	22	32
#4 (4.76 mm)	35-56	45	23	55
#8 (2.36 mm)	23-38	30	15	70
#20 (0.85 mm)	13-27	20	10	80
#40 (0.425mm)	8-12	10	10	90
#200 (0.075 mm)	2-8	5	5	95
Pan				100

2.3. Mineral fillers

Mineral fillers are defined as any product that passes sieve #200. In this research, four different types of filler materials were used to make a comparison between the effect of each one on the permanent deformation of asphalt mixtures. These filler materials are shown in Fig. 2 and the descriptions of these fillers are listed below.



Limestone dust **Waste toner** **Waste glass** **Waste rubber** **EAFD**

Fig. 2. Filler materials used in this research.

2.3.1. Limestone dust

Limestone dust is one of the components of the limestone aggregate brought from the Irbid quarries in Jordan. Limestone is a sedimentary rock composed mainly of calcite and aragonite. This limestone aggregate is used in the construction of Hot Mix Asphalt (HMA) in the northern parts of Jordan because the aggregates are available and cheap. The raw aggregate was sieved and the part passing sieve #200 was used as the limestone dust.

2.3.2. Waste toner

Toner is solid powder that is used in the cartridge of printers and copiers. 9000-25000 tons of toner is produced each year in the United States [31]. Waste toner is the toner that exists in the cartridges after use or when the manufactured toner does not meet specifications. This waste toner can be used as a modifier in asphalt mixtures. This filler type was collected from copiers and printers in the printing shops in Irbid, Jordan. Yordanova et al. [32] studied the chemical components of powder toner, and these components are presented in Table 4. The waste tonner was sieved and the portion passing sieve #200 collected.

Table 4. Chemical compositions of waste toner, waste glass, waste rubber, and electric arc furnace dust.

Waste toner [32]		Waste glass [1]		Waste rubber [14]		Electric arc furnace dust [19]	
Element	**Content (%)**	**Chemical component**	**Content (%)**	**Chemical composing**	**Content (%)**	**Chemical component**	**Content (%)**
Si	7.050	SiO_2	29.17	Acetone extract	13.40	Fe_2O_3	39.3
Al	0.120	Al_2O_3	18.85	Sulphur	2.36	MnO	2.00
Ti	0.800	Fe_2O_3	6.97	Carbon black	31.70	TiO_2	0.34
Ba	0.030	CaO	16.51	Ash content	6.10	CaO	8.96
Ca	0.470	MgO	2.60			K_2O	0.25
Mg	0.040	Na_2O	10.72			P_2O_5	0.35
Na	0.200	K_2O	0.65			SiO_2	6.20
K	0.100	SO_3	0.87			Al_2O_3	1.52
Fe	57.860	$CaCO_3$	-			MgO	3.22
Cu	0.220	Other	13.66			Na_2O	3.87
Zn	0.680					SO_3	2.50
Cr	0.040					CI	5.27
Ni	< 0.001					ZnO	18.7
Mn	0.030					LOI	7.00
Co	< 0.001					Others	0.52
Pb	<0.001						

2.3.3. Waste glass

About 10 million tons of waste glass is discharged around the world every year, and hundreds of tons are discharged every year in Jordan [9, 10]. Waste or recycled glass can be melted and reformed or used in asphalt mixtures because it does not burn or explode when added to the asphalt mix. Waste glass can be used after crushing and sieving to replace aggregate. The waste glass used in this study was brought from a factory in Irbid that manufactures windows. Waste glasses were collected, crushed and then sieved to collect the portion that passed sieve #200. The composition of the waste glass [1] is shown in Table 4.

2.3.4. Waste tire rubber

Due to the large increase in traffic volume around the world, the amount of end life tires has increased. About 300 million scrap tires are produced in the United States every year [14]. These tires can be reused in the construction of asphalt pavements. There are two processes to modify a mixture - the dry process and the wet process. In the dry process, waste rubber replaces aggregate while in the wet process waste rubber is added to the asphalt and mixed with it [33]. The waste

tire rubber used in this research was brought from the North Factory for Rubber and Playground in Al-Ramtha in Jordan. This factory collects waste tires, pulls the steel out and grinds the remaining rubber. The waste rubber was sieved and the portion passing sieve #200 collected. The chemical components of the waste rubber [14] are presented in Table 4.

2.3.5. Electric Arc Furnace Dust

Electric arc furnace dust (EAFD) is by-product of steelmaking. In Jordan, between 1650 tons and 3000 tons of EAFD are produced every year [17]. This product is harmful and dangerous because it contains oxidic materials. However, EAFD can be used to modify the performance of asphalt mixtures through stabilization [17]. In this process, EAFD is mixed with asphalt at high temperature. For this research, EAFD was brought from the steel factory in Amman, Jordan. The chemical compositions of the EAFD are presented in Table 4. The material was sieved and the portion passing sieve #200 collected.

3. Laboratory Work

This section describes the laboratory work undertaken to achieve the research objectives. Figure 3 shows schematic representation of laboratory work.

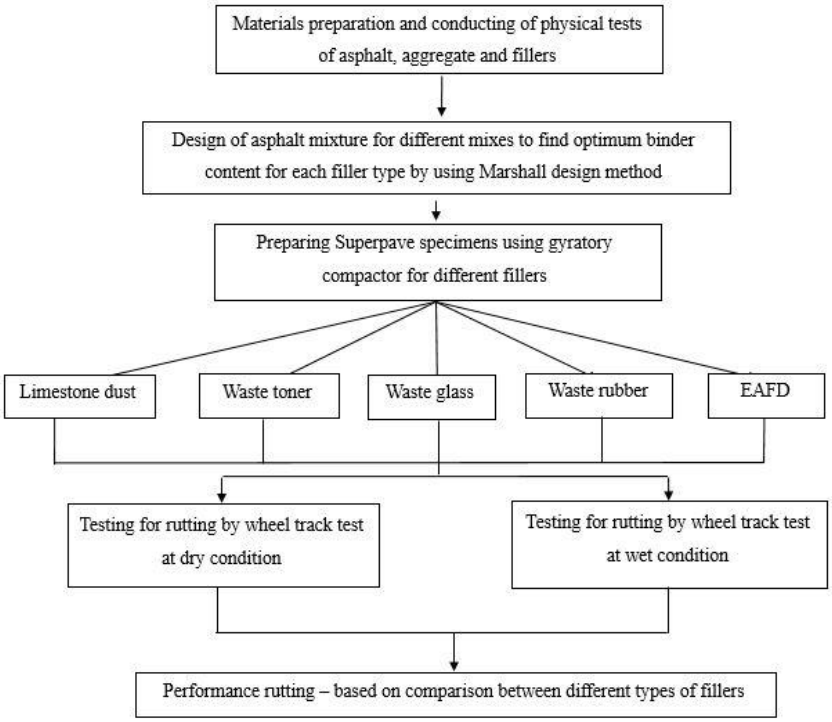


Fig. 3. Representation of the plan for the experimental work.

3.1. Preparation of aggregates

The aggregates were sieved then the gradation was selected according to MPWH (2010) [30]. Four aggregates samples with 1200 mg were prepared for each

asphalt content, three for compaction and one to find the maximum theoretical specific gravity. Aggregates were heated at 150˚C for 24 hours according to ASTM D1559 [34].

3.2. Preparation of the mixtures

Asphalt binder with penetration grade of (60-70) was heated to 150˚C for 2 hours before mixing with the heated aggregate. The molds and bowl were also heated. A hot plate was used during manual mixing of the materials. Asphalt was added to each aggregate sample according to the content of asphalt of 4%, 4.5%, 5%, 5.5% and 6%. The specimens were compacted with a Marshall compactor. A jack hammer with a mass of 4.5 kg falls freely for a distance of about 18" (~ 46 cm) applying 50 blows on each face of the specimen to simulate the wheel loads of medium traffic that will be passing on the pavement. The specimens were extracted from the molds after 24 hours according to ASTM D1559 [34].

3.3. Determine the Optimum Binder Content (OBC)

The Standard American Institute MS-2 Manual (2008) [35] and ASTM D1559 [34] were used to determine the OBC using the Marshall design method. Each specimen was tested for specific gravity. ASTM D2726 [36] is used to determine the bulk specific gravity (G_{mb}) by taking three weights, air dry weight A, saturated surface dry weight B, and submerged weight C. ASTM D2041 [37] was used to determine the maximum theoretical specific gravity (G_{mm}).

The Marshall stability and flow can be found for the specimens using the Marshall stability test. After that, six charts were plotted to show the relationships between the asphalt content versus stability, flow, unit weight, air void, voids in mineral aggregate and voids filled with asphalt. The OBC is equal to the average value of three asphalt contents that meet maximum stability, maximum unit weight, and 4% air voids.

3.4. Permanent deformation of modified asphalt mixture by wheel tracking test

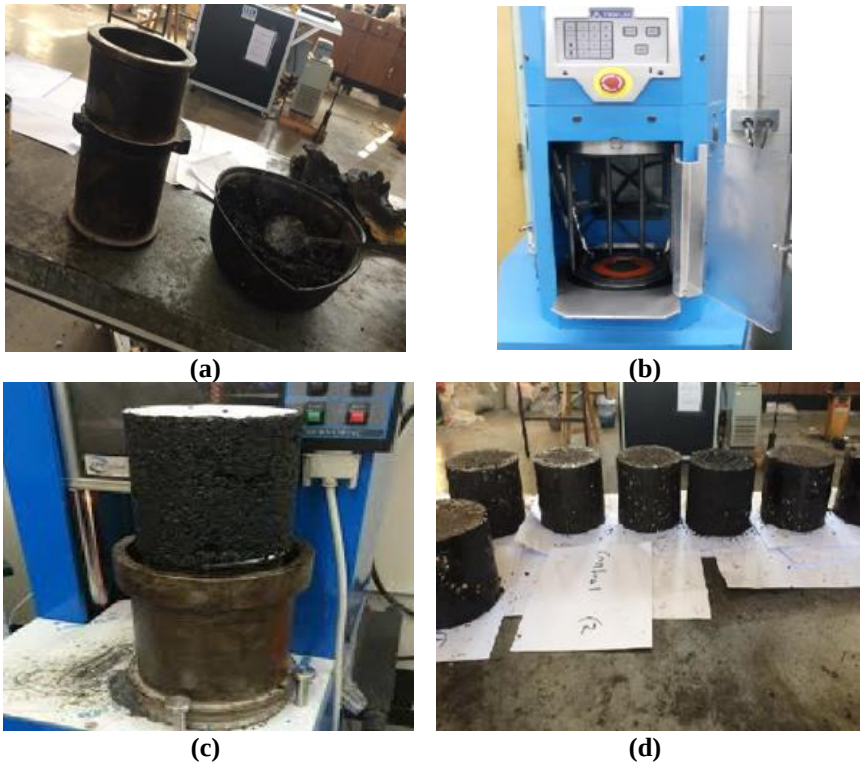
Permanent deformation or rutting is defined as one of the distresses that occur in flexible pavements. This distress is a continuous depression in the pavement surface along the pathway of traffic and is noticeable during the hot weather. Rutting is caused by many factors such as repeated traffic loading, high temperature, tire pressure, speed of vehicle and construction material properties [38]. To find the rutting of asphalt mixtures, there are many tests that can be carried out such as static creep, dynamic creep and the wheel tracking test.

The wheel tracking test is an empirical test used to find the rutting of asphalt mixtures by applying specific moving loads on a specimen of asphalt mixture and measuring the rutting depth through a linear variable differential transformer (LVDT) that is attached to the specimen during the test. The wheel tracking test uses different types of devices such as the Hamburg Wheel Track (HWT), the Asphalt Pavement Analyzer (APA) and the French Rutting Tester (FRT) [39]. The specimens tested in the wheel tracking test may be slabs or cores. These specimens can be prepared in the laboratory or can be brought from the field. The wheel tracking test can be used to investigate the effect of hot weather on the asphalt

mixture by testing the specimens under dry conditions at elevated temperatures up to 70˚C. Also, the effect of moisture on the rutting can be found through submerging the specimens in water at high temperature during the test [40].

To find the permanent deformation of the modified mixtures, the wheel tracking test was applied on each specimen. The following steps explain this experiment:

- Find the OBC for each filler material by Marshall design method.
- This OBC was used to prepare a Superpave sample of 4500mg of aggregate with the same gradation as the Marshall samples using the MPWH (2010) [30] specifications, specified by 6" diameter and 4.8" selected height of the specimen, that is controlled to finish compacting using a Superpave gyratory compactor according to [41]. This step is shown in Fig. 4.
- Cut each specimen into two nominally identical parts with height of 2.2" to insert each part in the mold. This step is shown in Fig. 5(a).
- Test the two specimens together under dry condition. The parameters of this test were the temperature of chamber (50˚C) and the load of wheel (705 N) according to [42] and the number of passes for wheels (10000 passes). Samples in the wheel tracking device is shown in Fig. 5(b).
- Fill the chamber of the wheel tracking device with water then heat to 50˚C and test the other group of specimens under the effect of moisture.



(a) **(b)**

(c) **(d)**

Fig. 4. Preparation of Superpave mixtures: mixing Superpave sample (a), gyratory compactor (b), extrude Superpave sample (c), and order the samples for cutting.



(a) **(b)**

Fig. 5. Cutting of Superpave sample (a) and samples in the wheel tracking device (b).

4. Analysis and Discussion of Results

4.1. Marshall test

The properties obtained from the Marshall test including the Marshall stability and flow values, density and void parameters for the surface course of the HMA according to MPHW (2010) [30] are given in Table 5. Void parameters (voids in the total mix (VTM), voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA)) were also obtained.

Table 5. The properties of Marshall test according to MPHW (2010) [30].

Asphalt grade	Stability (kN)	Flow (0.25 mm)	Air void %	VMA %	VFA %
60-70 or 80-100	5.35	2-4	3-5	> 13	65-78

4.1.1. Effect of fillers on the Optimum Binder Content (OBC)

The optimum binder content (OBC) is obtained by taking the percentage of asphalt content that corresponds to maximum stability, maximum unit weight and 4% air voids. Figure 6 shows the relationship between the type of filler and OBC.

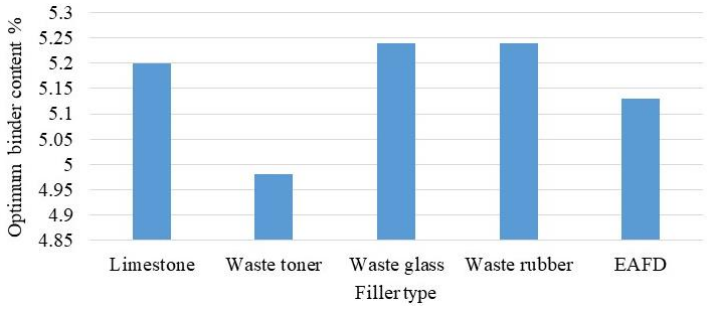


Fig. 6. Relationship between filler type and optimum binder content.

According to Fig. 6, waste toner modified asphalt mixtures have the lowest OBC (4.98%) which was reduced by 4.23% from the limestone asphalt mixture samples. The OBCs with the other fillers were near to the OBC for the limestone asphalt mixture samples. The reduction of binder content in waste toner is explained by the absorption of the aromatic oils presented in the asphalt which is large in waste toner asphalt mixtures and the asphalt is mixed well [6]. On the other

hand, waste glass has silica particles that bond well with asphalt and require more asphalt in the mixture [7].

4.1.2. Effect of fillers on the Marshall stability

The Marshall stabilities for the mixtures at OBC are presented in Fig. 7. From Fig. 7, Marshall stability for all modified mixtures satisfied the Marshall criteria since all of the Marshall stabilities for modified mixtures are larger than 5.35 kN according to Table 5. Waste toner modified mixtures have the highest stability. This stability is larger than that of the reference mixtures by 159%. This may be explained by waste toner contained styrene acrylate copolymer and small amount of wax that enhance mechanical properties of the mixtures [1]. Waste rubber and electrical arc furnace dust (EAFD) have the same effect on the stability, these stabilities are larger than limestone modified mixture by 72%. When waste rubber is added to the mixture spring action will develop and the cohesion with the asphalt will be reduced [33]. Waste glass has a negative effect on Marshall stability, reducing it by 5%. This reduction in stability is due to that mix having silica particles with reduced adhesion with the asphalt.

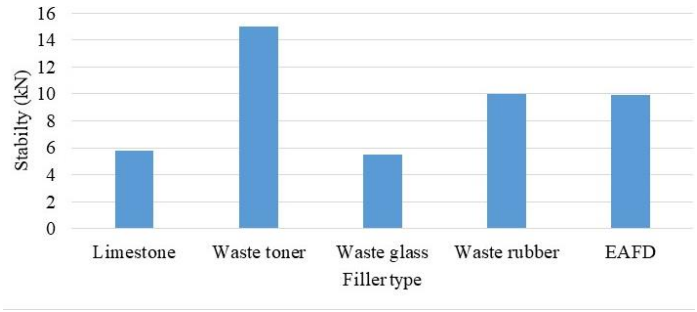


Fig. 7. Relationship between filler type and Marshall stability.

4.1.3. Effect of fillers on the flow value

Figure 8 shows the flow values at OBC for different modified mixtures. The flow values for all modified mixtures satisfied the Marshall criteria since all of the values for modified mixtures are within the range of 2 to 4 mm (Table 5). Also, it is clear that waste toner reduced the flow value by 21% compared with the unmodified mixture due to the high absorption of asphalt. The Marshall stiffness is defined by ratio of Marshall stability divided by flow value.

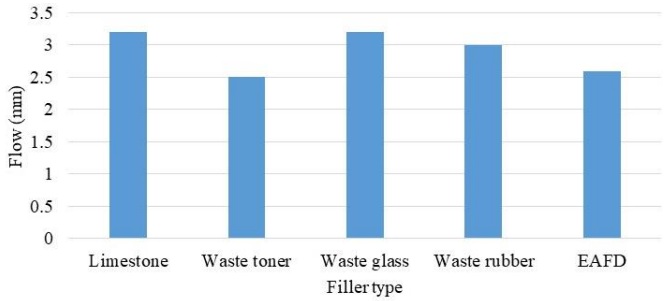


Fig. 8. Relationship between filler type and flow values.

Figure 9 gives Marshall stiffness for different mixtures by taking the ratio of stability to flow. From Fig. 9, Marshall stiffness for waste toner, waste rubber and EAFD modified mixtures are larger than control mixture by 213%, 84% and 112% respectively. On the other hand, the Marshall stiffness of the waste glass modified mixture was lower by 5% and this result about waste glass contradicts the results of [1, 10, 12, 13]. This performance is explained in section (4.1.2). Extra variety of blends may improve the result since waste glass filler can be blended with lime to enhance its property, the use of waste glass as a partial replacement of limestone dust is preferable instead of full replacement.

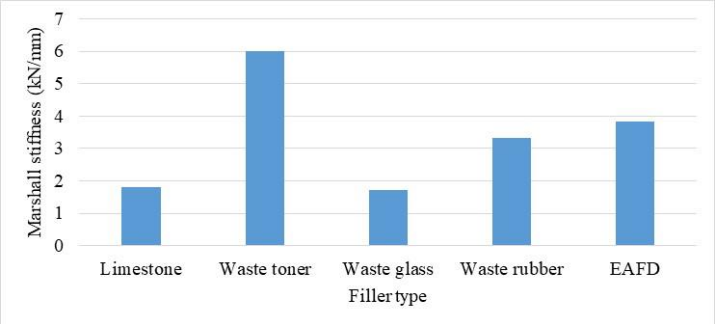


Fig. 9. Relationship between filler type and Marshall stiffness.

4.1.4. Effect of fillers on the unit weight

The unit weight of a sample is defined by mass divided by volume. The unit weights of modified samples are presented in Fig. 10. Only the EAFD modified mixtures have unit weight larger than control mixture because the specific gravity of EAFD is larger than specific gravity of limestone dust. In contrast, waste toner, waste rubber and waste glass have unit weights lower than control mixture by 3% because these fillers have specific gravity lower than specific gravity of limestone dust [12, 17].

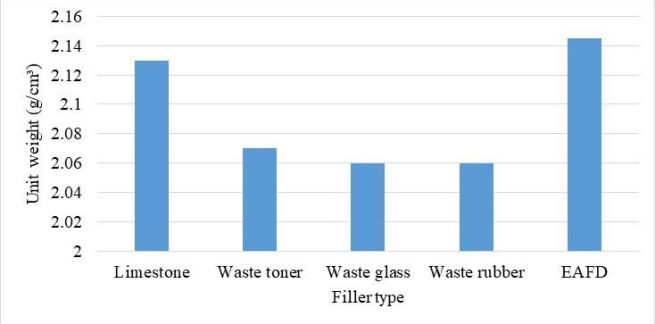


Fig. 10. Relationship between filler type and unit weight.

4.1.5. Effect of fillers on Voids in Mineral Aggregate (VMA)

VMA is intergranular space occupied by air and asphalt. The VMA for modified mixtures are presented in Fig. 11. Values of VMA varied from 19% to 22%, and these values satisfied the condition in the Marshall criteria because these values are larger than 13% according to Table 5.

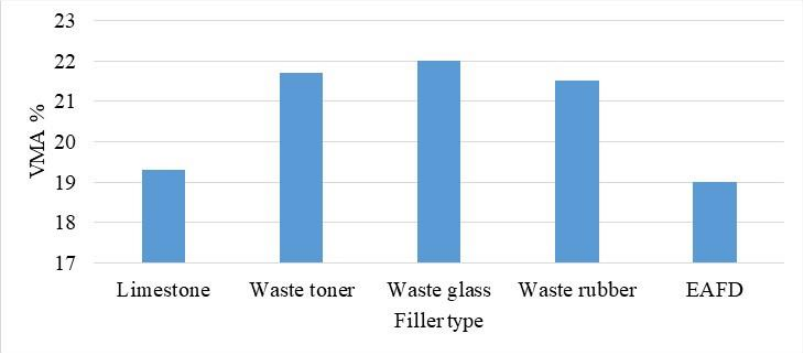


Fig. 11. Relationship between filler type and VMA.

4.1.6. Effect of fillers on Voids Filled with Asphalt (VFA)

VFA is the portion of the VMA filled with bitumen and it depends on the volume of air in the mixture. The effect of filler types on the mixture is presented in Fig. 12. The values of VFA ranged from 75% to 83% with the highest value for waste toner modified mixtures due to the absorption of the aromatic oils presented in the asphalt which is large in waste toner asphalt mixtures.

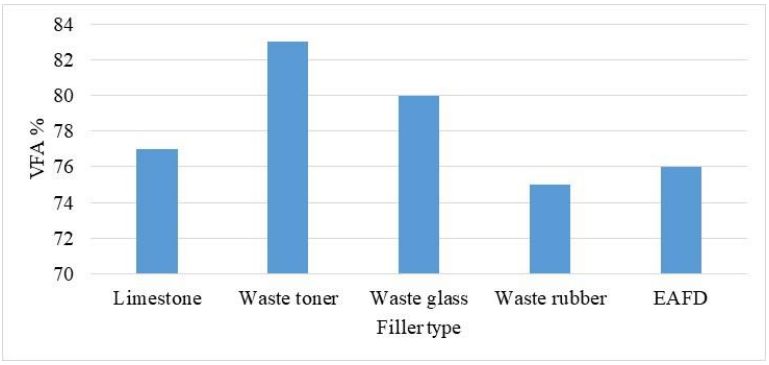


Fig. 12. Relationship between filler type and VFA.

4.2. Wheel Tracking Test

4.2.1. Wheel tracking test at dry condition

In this test, Superpave samples were tested at dry condition with temperature of 50ºC. Table 6, Figs. 13 and 14 show the effect of filler types on the rutting of asphalt mixture when tested under dry conditions.

When the number of passes reaches to 10000 passes, the waste toner modified mixture has the best rutting resistance. The substitution of waste toner reduced the rutting by 82.2% compared to limestone dust. Waste toner modified mixtures have the highest values of stability, stiffness and VFA. Also, waste rubber and EAFD reduced rutting by 43.6% and 28.7% respectively. In contrast, waste glass had a negative effect on the rutting resistance - it increased the rutting by 64.3%. Waste glass modified mixtures have the lowest values of stability and stiffness.

Table 6. Rut depth in unit of (mm) of modified mixtures at dry and wet conditions at 50ºC for different passes levels.

Type of filler	Dry			Wet		
	No. of passes					
	1000	**4000**	**10000**	**1000**	**4000**	**10000**
Limestone	4.03	6.4	10.1	10.2	14.6	22.4
Waste Toner	0.12	0.48	1.8	4.1	7.1	9.4
Waste Glass	7.7	13.1	16.6	12.7	20.8	27.6
Waste Rubber	1.3	3.1	5.7	6.3	8.6	15.1
EAFD	2.9	4.8	7.2	8.1	12.1	19.2

When the number of passes reached 4000 passes, waste toner, waste rubber and EAFD reduced rutting by 92.5%, 51.5% and 25% respectively but the waste glass doubled the rutting. This variance in the results is explained by surface texture of the filler which is a function of rutting resistance. The surface of glass is smooth so that the rutting resistance is small [11], but in waste toner, the surface texture is rough and aggregate interlock is strong to resist rutting. Waste toner modified mixtures exhibit high rut resistance when compared to conventional mixtures (Huang et al. [43]).

EAFD works as filler material to pores and is a good bonding agent between asphalt and aggregate [16]. Also, the existence of rubber in the mixture enhances the permanent deformation resistance [44].

4.2.2. Wheel tracking test under wet condition

In this test, the samples were submerged in hot water at 50ºC for 2 hours, then tested with the wheel tracking machine. In this test, Table 6, Figs. 15 and 16 show the effect of filler types on the rutting of asphalt mixture.

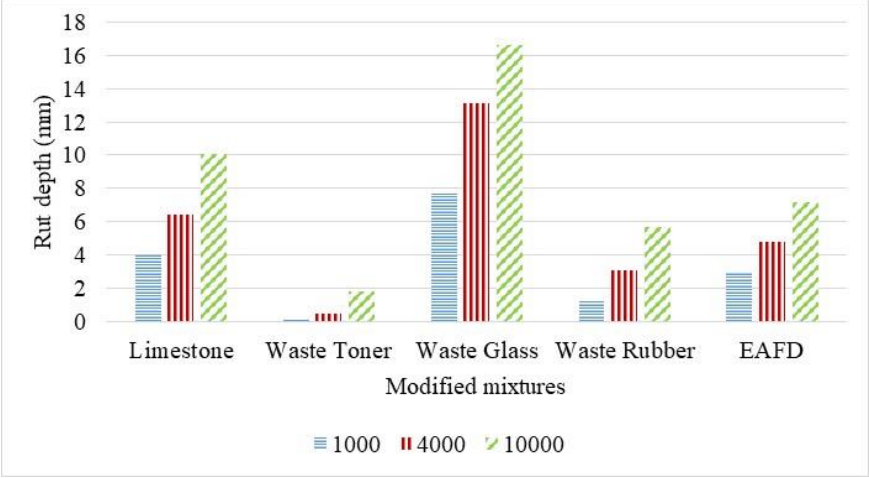


Fig. 13. Rut depth of modified mixtures at dry condition at 50ºC for different number of passes.

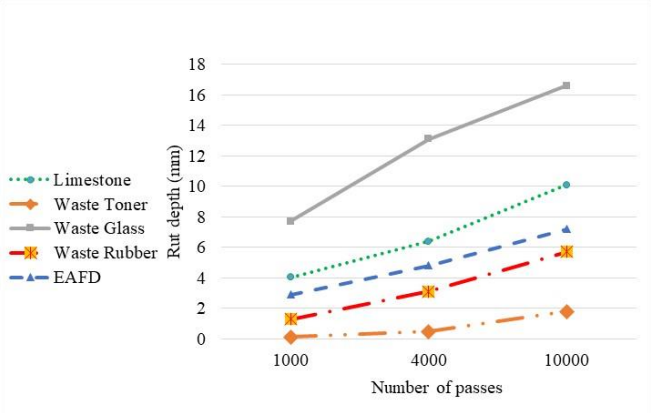


Fig. 14. Rut depth of modified mixtures at dry condition at 50ºC for different number of passes.

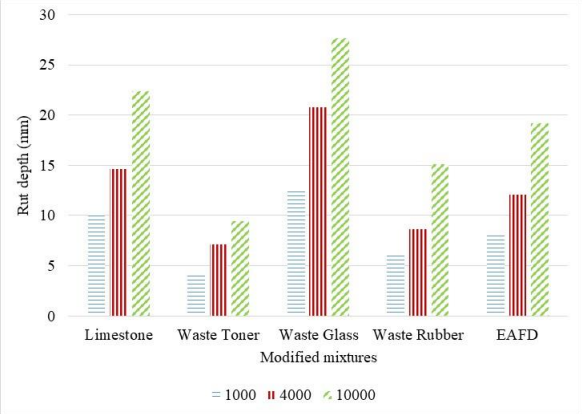


Fig. 15. Rut depth of modified mixtures at wet condition at 50ºC for different number of passes.

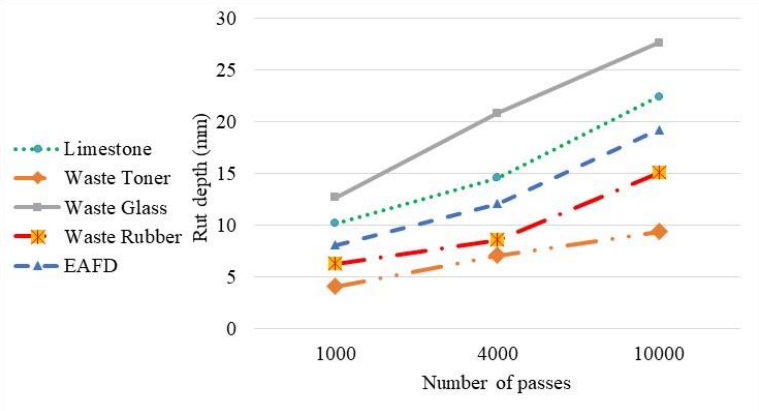


Fig. 16. Rut depth of modified mixtures at wet condition at 50ºC for different number of passes.

When the number of passes reached 10000 passes, waste toner modified mixture had the best rutting resistance, reducing the rutting by 58%. Waste toner modified mixtures have the highest values of stability, stiffness and VFA. Also, waste rubber and EAFD reduced the rutting by 32.5% and 14.2% respectively. In contrast, waste glass had a negative effect on the rutting resistance, increasing the rutting by 23.2%. Again this is because waste glass does not have good bond with asphalt due to the high content of silica that makes waste glass powder a hydrophilic material, in addition to the chemical exchange between silica and asphalt making a weak bond between them [9]. Waste glass modified mixtures have the lowest values of stability and stiffness.

When the number of passes reached to 4000 passes, waste toner, waste rubber and EAFD reduced rutting by 53.1%, 41.1% and 17.1% respectively while the waste glass increased rutting by 42.4%.

The wheel tracking test was conducted for 10000 passes of moving load on Superpave specimens. The results showed that permanent deformation of specimens modified by waste toner, waste rubber and electric arc furnace dust would be lower than limestone asphalt mixtures, but waste glass filler material had increased permanent deformation compared with the limestone asphalt mixtures for both dry and wet conditions. The chemical composition of filler material could affect the filler-bitumen interaction and, consequently, the resistance to permanent deformation. The paper discussed the rutting resistance in relation to Marshall's properties.

5. Conclusions and Recommendations

The paper concerns asphalt mixtures to be used in pavements. It presents laboratory research on the effect of filler materials, an important component of asphalt mixtures, from waste materials on the Marshall properties and the rutting resistance. In the rutting evaluation, the research used the wheel tracking test. Based on the results of this study, the following conclusions can be drawn for the tested asphalt concrete of maximum particle size 19.5 mm:

- Marshall tests showed that using waste toner, waste rubber and electric arc furnace dust will enhance the Marshall properties, but waste glass modifier will have a negative effect on Marshall properties. Extra variety of blended may improve the result since waste glass filler can be blended with lime to enhance its property, the use of waste glass as a partial replacement of limestone dust is preferable instead of full replacement.
- Using of waste toner as filler material will reduce OBC by 4.23%. The reduction of binder content in waste toner is explained by the absorption of the aromatic oils presented in the asphalt which is large in waste toner asphalt mixtures
- Replacing of limestone dust by waste toner, waste rubber and electric arc furnace dust will reduce permanent deformation about 82% at dry condition and about 58% at wet condition for waste toner.
- Waste glass filler is a negative agent on the permanent resistance of bituminous mixtures. Replacing of this filler by limestone dust will increase permanent deformation by 64% at dry condition and by 23% at wet condition.
- Waste toner filler material is the best filler in this study, as it enhanced Marshall properties and increased rutting resistance with the highest proportions.

According to the results of this research, it is recommended to:

- Investigate the effect of used filler materials on the asphalt binder (AC) properties when they are used together with specific weight ratios.
- Evaluate the effect of used filler materials on the Superpave asphalt binder properties.
- Carry out rheology tests on the mastic made up of the fillers and the asphalt binder.
- Test a slab of HMA prepared by Superpave method to find the correlation between the rutting depth of cores and slabs with the same asphalt and aggregates specifications.
- Further, evaluate the effect of different temperatures and load cycles on the modified asphalt mixtures to build a correlation between rutting and these factors.
- Carry out a deeper mineralogical and chemical characterization (e.g., X-ray diffraction, X-ray fluorescence, Scanning electron microscopy observations, etc.).

This research has set an additional step for future work. Some of the suggestions are given to whom it may concern of this research:

- Waste glass filler can be blended with lime to enhance its properties in the resistance to permanent deformation.
- Adding these fillers to the mixtures instead of replacing limestone dust to save time and effort.
- Adopting the use of waste toner as a filler material in the construction of hot mix asphalt in projects.
- Associating the cost-effective benefits of replacing limestone dust by other types of fillers.

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