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A Comparative Study of Utilizing Two Kinds of Reclaimed Asphalt Pavement Materials in Hot Mix Asphalt

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ABSTRACT

Currently, in the last decade, a great number of new highways were constructed in Egypt to encourage and facilitate the investment projects. So, a lack of the abundance of quality and quantity of good virgin aggregate is becoming a great problem facing highway construction firms. So, new alternative materials should be discovered to overcome this great problem. The purpose of this study is to make a comparison between utilizing two kinds of reclaimed asphalt pavement materials in hot mix asphalt. To implement this objective, a comprehensive experimental plan was designed. Qualification tests were performed on the study materials. Two kinds of study materials were used in this study; calcareous reclaimed asphalt pavement (RAP) and dolomite reclaimed asphalt pavement. Different percentages of virgin aggregates were used with complementary percentages of RAP in each asphalt mix. Marshal tests were performed to determine Marshal properties and optimum asphalt content in each asphalt mix. Indirect tensile strength test and loss of stability test were conducted on each prepared asphalt mix. After the analysis of study results, it is found that increasing the percentage of reclaimed asphalt pavement will decrease the characteristics of asphalt mixture, at a specific percentage of asphalt content. Also, the ideal percentage of RAP to be utilized in flexible pavement is 25% of calcareous RAP and 30% of dolomite RAP.

1. Introduction

There are many types of bituminous pavement rehabilitation. These types include reconstruction, recycling and overlying. Factors govern the selection of the suitable type of bituminous pavement rehabilitation are design parameters, available funding, laboratory and field evaluation of existing pavement materials and pavement distresses.

Recycling is defined as the fully or partially reused of materials from deteriorated pavement in new pavement construction [1], [2]. There are many advantages for applying recycling process such as preservation of environment, decreasing user delay, saving of pavement materials and decreasing the construction cost [3].

Also, in the modern countries millions of tons of old pavements are collected every year which represent an environmental problem in these countries [4], [5]. Focusing especially on the

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conservation of large quantities of collected old pavements materials and to benefit from it, recycling, had urged some governments to study the characterization of the mechanical properties of recycled asphalt materials [6], [7]. Construction of new highways is consuming large quantities of aggregates. In the last few years, using of recycled pavement materials in new pavements is steadily increasing. Regardless of the age of old pavement, the produced asphalt binder and aggregate are still valuable. There are many types of recycling such as hot recycling in plant and hot recycling in situ [8], [9], [10]. Mengqi et al [11] has concluded that the range between 5% and 50% reclaimed asphalt pavement (RAP) can be used in highway construction, Decker et al [8], [12], [13] stated that a percent above 50% of RAP can be used to obtain new hot mix asphalt mixtures with acceptable results of mechanical properties. On the other hand, Harrington et al [14], [15], [16] concluded that a 100% of RAP can be used to obtain new asphalt mixtures. The resulting asphalt mixture containing 100% RAP has an adequate performance under the condition of a grantee of adequate control of production [8], [13], [17], [18]. Rebbechi et al [19] concluded that the factors affecting the stiffness modulus of recycled asphalt mixture are aggregate type, aggregate gradation and the stiffness of aged asphalt binder in the reclaimed asphalt pavement. Al-Kandari et al [20] concluded that a 25% of RAP can be used to produce asphalt mix with acceptable properties according Kuwait specifications. Saad et al [21] stated that using o specific percentage of RAP improves the properties of hot mix asphalt. Alzubaid et al [22] concluded that using of RAP improves the stiffness of asphalt mix. Sarsam et al [23] found that using of RAP increases the tensile strength of asphalt mix. Zhang et al concluded that the increasing of RAP percentage will reduce the energy consumption by 7 to 10% and will decrease the CO_2 emission by 8 to 10% [24]. Ali et al revealed that using percentage of RAP more than 25% will decrease the characteristics of asphalt mix such as stability and resistance to cracking and rutting [25]. Guangwei, et al concluded that using of RAP produces sustainable benefits and has a great contribution in reduction of the emissions of greenhouse gas and saving the natural resources [26]. Abdulmawjoud revealed that marshal stability had increased by 20% at 30% RAP. Also, flexural modulus and tensile strength ratio had increased by 4.5% and 100% respectively. Also, rut depth, fatigue life and cohesion value had decreased 46%, 74%, and 13% respectively [27]. Nasser et al revealed that using RAP materials enhanced the Marshal stability of hot mix asphalt [28]. Investigation of the effect of using two kinds of RAP materials on the properties of asphalt mix is the main purpose of this study.

2. Problem Statement

The national project for road construction in Egypt aims at constructing 40 new pivotal highways to connect different road axes with a length of more than 3000 km. In addition, another 1000 km. are currently constructed through the annual plan of Egyptian government. The construction of new highways requires huge amounts of aggregates. There is a shortage in the availability of quantity and quality of virgin aggregate. This problem increased as a result of constructing new roads as well as maintaining the existing roads. An innovative construction techniques and alternative construction materials have turned to be an essential goal.

One of the most serious problems resulting is the huge amounts of materials resulting from removing the old pavement layers in case of maintenance and rehabilitation of highways. These materials are considered waste materials and not used as recycled materials. The huge amounts of such materials are occupying wide spaces of the road sides that can be used in planting green areas. So, reusing of these huge amounts of old pavement materials, which is called recycling, is considered an innovate solution innovate solution for these problems.

3. Study Objectives

This study aims at investigating the reuse of two different RAP materials in hot mix asphalt, evaluating the effect of using these two RAP materials on asphalt mix performance, studying the effect of aging on the two RAP asphalt mixes and determination of the optimum percent of the two RAP materials in asphalt mix.

4. Materials and Program of Experimental Testing

An experimental program was designed to achieve the study objectives. This program includes several steps. Collection of the study materials was the first step. Study materials include virgin aggregate, recycled materials and asphalt binder. The Suez asphalt cement with penetration grade 60/70 and specific grade 1.02 was used in this study. Two types of recycled materials were used in this study. These two types were dolomite RAP and calcareous RAP. Dolomite RAP was collected from Zagazig – Belbais road while calcareous RAP was collected from Domiate – Port Said road. The source of used virgin aggregate was Suez quarries. Material evaluation tests were conducted on the collected virgin materials. After that, the characterization tests for the investigated RAP materials were conducted to determine the asphalt content and aggregate gradation by extraction test. Several samples of asphalt mix were prepared in groups. Each group contained different percentages of virgin aggregate and complementary percent of the two types of RAP materials. The different percentages of the two RAP materials were 0%, 10%, 20%, 25%, 30% and 40%. OAC and different properties of each specimen were obtained after performing Marshall tests on all the investigated asphalt mixes. These different properties were voids in mineral aggregate (VMA), density, air voids, flow, and stability. The last step of the experimental program was to conduct some special tests to determine the behaviour of the investigated asphalt mixtures. These tests were loss of stability test and indirect tensile strength (ITS) test. Mix gradation used in this study was (4-C).

4.1. Tests of material evaluation

Laboratory tests performed in this study include two groups. The first group contains qualification tests of aggregate, while the second concerns with the asphalt material. The qualification tests of virgin aggregate include gradation, specific gravities, absorption, disintegration and Los Angeles abrasion tests. Table 1 shows the standard mix gradation (4C) and the actual mix gradation. Tables 2, 3, 4, 5 show the different properties of coarse aggregate, fine aggregate and mineral filler. For the binder, the tests include penetration, flash point, softening point and viscosity tests. Table 6 presents the characteristics of used asphalt binder. From the previous tables it is obvious that all these materials were accepted.

Table 1: Standard mix gradation and the actual mix gradation

Sieve opening	% Passing	
	Specification limits for (4-C)	Actual gradation
1”	100	100
¾”	80 – 90	97.8
½”	-----	85
3/8”	60 – 80	68.8
No. 4	48 – 65	48.5
No. 8	35 – 50	41.1
No. 30	19 – 30	24.5
No. 50	13 – 23	17.3
No. 100	7 – 15	9.2
No. 200	3 – 8	6.3

Table 2: Gradation of coarse aggregate

Size of sieve	% passing	
	Aggregate 1	Aggregate 2
3/4"	100	91
1/2"	100	35
3/8"	90	5
No. 4	20	0
No. 8	4.3	0
No. 30	2.9	0
No. 50	2.7	0
No. 100	2.4	0
No. 200	2.2	0

Table 3: Coarse aggregate properties

<table>
<tr><th rowspan="2">Test No.</th><th rowspan="2" colspan="2">Test</th><th rowspan="2">Design.</th><th colspan="2">Results</th><th rowspan="2">Spec. limits</th></tr>
<tr><th>Agg. 1</th><th>Agg. 2</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Spec. grav.</td><td>Bulk</td><td rowspan="4">AASHTO T-85</td><td>2.513</td><td>2.44</td><td rowspan="3">---</td></tr>
<tr><td>Sat., surface-dry</td><td>2.568</td><td>2.532</td></tr>
<tr><td>Apparent</td><td>2.66</td><td>2.681</td></tr>
<tr><td>2</td><td colspan="2">Water absorption, %</td><td>2.2</td><td>3.6</td><td>≤ 5</td></tr>
<tr><td>3</td><td colspan="2">Los Angeles abrasion, 100 revolution, %</td><td rowspan="2">AASHTO T-96</td><td>7</td><td>6</td><td>≤ 10</td></tr>
<tr><td>4</td><td colspan="2">Los Angeles abrasion, 500 revolution, %</td><td>31</td><td>32</td><td>≤ 40</td></tr>
</table>

Table 4: Sand gradation

Sieve size	% passing
No. 4	96.6
No. 8	93
No. 30	60.4
No. 50	30
No. 100	9
No. 200	3

Table 5: Gradation of mineral filler

Size of Sieve	% passing	Spec. limits
Number 30	100	100
Number 50	98	--
Number 100	93	≥ 85
Number 200	81	≥ 65

Table 6: Asphalt cement characteristics

No. of test	Test	Design.	Results	Spec. limits
1	Softening point (ºC)	AASHTO T- 53	51	45 – 55
2	Flash point (ºC)	AASHTO T- 48	269	≥ 250
3	Kinematic viscosity (centistokes, 135ºC)	AASHTO T- 201	345	≥ 320
4	Penetration (0.1 mm.)	AASHTO T- 49	62	60 – 70

4.2. Characterization tests

The characterization tests for the investigated RAP materials include extraction, sieve analysis and Los Angeles abrasion tests. These tests were performed according to AASHTO T 96. Tables 7, 8 show the results of these tests.

Table 7: Results of Los angles tests for dolomite and calcareous reclaimed asphalt pavement

No.of test	Test	Design.	Result	Spec. limits
1	Dolomite Los angles abrasion, 100 revolution, %	AASHTO T-96	6	≤ 10
2	Dolomite Los angles abrasion, 500 revolution, %		30	≤ 40
3	Calcareous Los angles abrasion, 100 revolution, %		9	≤ 10
4	Calcareous Los angles abrasion, 500 revolution, %		37	≤ 40

Table 8: Sieve analysis test results after extraction test of the dolomite RAP and calcareous Rap

Sieve size	Recycled material gradation for dolomite RAP			Recycled material gradation for calcareous RAP			Spec. limits 4C
	Sam-ple 1	Sam-ple 2	Av.	Sam-ple 1	Sam-ple 2	Av.	
3/4"	100	99	99.5	100	99	99.5	100
1/2"	85	89	87	91	87	89	----
3/8"	75	79	77	70	82	76	60 = 80
No. 4	45	52	48.5	48	56	52	48 – 65
No. 8	30	36	33	36	33	34.5	35 – 50
No. 30	22	26	24	22	25	23.5	19 – 30
No. 50	12	14	13	15	17	16	13 – 32
No. 100	7	8	7.5	7	8	7.5	7 – 15
No. 200	4.3	5.4	4.85	4.3	4.1	4.2	3 - 8
A.C. %	4.42	4.78	4.6	4.38	4.58	4.48	

4.3. Marshall design test

Marshall test were performed to obtain OAC, stability, density, air voids, flow and VMA of the investigated asphalt mixes. This test was carried out in accordance with AASHTO T 245.

4.4. Indirect Tensile Strength (ITS) test

This test was developed in 1953 [29], [30]. The following equation was adopted to determine the indirect tensile strength (ITS) value of the investigated asphalt mixes [31]:

Indirect tensile strength value, psi = (load at failure, ib)/ (6.41 * Specimen height, in.)

4.5. Test of Loss of Stability

The aim of this test is to measure the resistance of asphalt mix to water action using reheated asphalt. This test was carried out in accordance with AASHTO T 165. Test specimens include both RAP and virgin aggregate. The temperature of water bath, in which the test specimens are placed, is 60ºC. Times at which test specimens are tested are 0.5 and 24 hours.

5. Results and Analysis

This part discusses the results and analysis of indirect tensile strength test, loss of stability test and Marshall test parameters for the investigated asphalt mixes used in this study. Marshall test parameters include optimum asphalt content (OAC), stability, density, flow, air voids and voids in mineral aggregates (VMA). Tables 9, 10 show the Marshall test results of the investigated asphalt mixes containing dolomite RAP and calcareous RAP respectively.

Table 9: Results of Marshall test for the investigated asphalt mixes containing dolomite RAP

% RAP	OAC	Density (gm. /cm^3)	Stab. (Ib)	Air voids %	Flow (0.01 in.)	VMA %
Virgin	5	2.435	4000	4.8	11	14.8
10% RAP	4.83	2.42	3350	4.2	12.2	15.1
20% RAP	4.7	2.41	3250	3.7	12.5	15.75
25% RAP	4.66	2.403	3100	3.4	14.8	16
30% RAP	4.5	2.387	3000	3.1	15.8	16.6
40% RAP	4.33	2.372	2700	2.4	18.3	18.6

Table 10: Results of Marshall test for the investigated asphalt mixes containing calcareous RAP

% RAP	OAC	Density (gm. /cm^3)	Stab. (Ib)	Air voids %	Flow (0.01 in.)	VMA %
Virgin	5	2.435	4000	4.8	11	14.8
10% RAP	4.86	2.392	3450	4.6	12	15.3
20% RAP	4.76	2.364	3200	4.1	13.1	15.5
25% RAP	4.66	2.337	3020	3.6	13.6	16
30% RAP	4.56	2.290	2700	2.75	14	16.3
40% RAP	4.5	2.258	2630	2.5	16.8	17

5.1. Marshall test results and analysis

5.1.1. Optimum asphalt content and absorbed asphalt results and analysis

Figure 1 presents the influence of utilizing various percentages of RAP materials on the OAC of the used asphalt mixtures. From this figure, it is obvious that OAC for both dolomite and calcareous RAP mixes decreases as the percentage of the reclaimed aggregates increases (inverse relationship). The reason for this result is the pores of the reclaimed aggregate were filled with old asphalt. For dolomite, OAC decreases from 5% to 4.33% due to increasing of RAP percentage from zero to 40%. This means that at using 40% of dolomite RAP, asphalt content saving reaches about 13.4%. For calcareous, OAC decreases from 5% to 4.5% due to increasing of RAP percentage from zero to 40%. This means that at using 40% of calcareous RAP, asphalt content saving reaches about 10%.

The asphalt content of asphalt mix can be divided into two parts. The first part is binder asphalt content and the second part is absorbed asphalt. The binder asphalt content is the amount of asphalt bonding the aggregates surfaces. The absorbed asphalt content is the amount of asphalt absorbed by coarse aggregates. Figure 2 shows the absorbed asphalt content for the investigated mixes at different percentages of RAP at OAC. From this figure it is obvious increasing the RAP percentage will decrease the absorbed asphalt percentage. The reason for this result is the new asphalt cannot occupy deeply in the aggregate pores due to the presence of old asphalt in the RAP aggregate pores. Also, The absorptiveness (ability to absorb asphalt) of calcareous RAP mixes are higher than the dolomite RAP mixes.

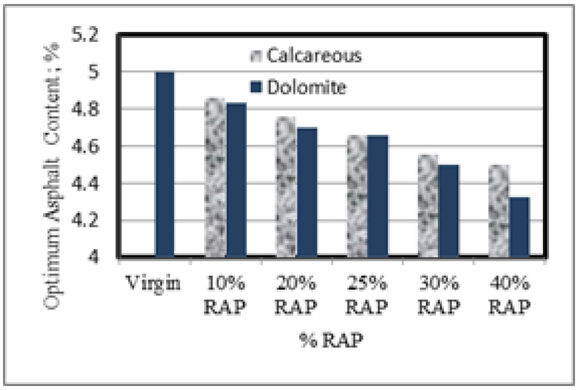

FIG. 1: Influence of utilizing various percentages of RAP materials on the OAC values of the used asphalt mixtures.

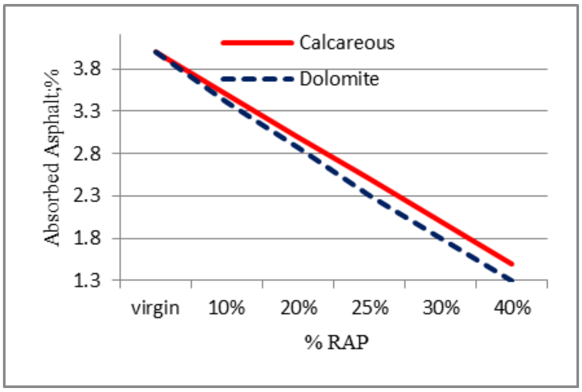

FIG. 2: Influence of utilizing of various percentages of RAP materials on the absorbed asphalt % of the used asphalt mixes.

5.1.2. Mix stability results and analysis

Figure 3 presents the influence of utilizing various percentages of dolomite and calcareous RAP on the values of stability of the used asphalt mixes. From this figure it is obvious that , for dolomite and calcareous RAP, stability value decreases due to increasing the RAP percentage. The fatigue of reclaimed aggregate by aging may be the cause for this result. For dolomite RAP, the percent of decreasing in stability values is 16.25%, 18.72%, 22.50%, 25% and 32.5% for 10%, 20%, 25%, 30% and 40% of RAP respectively comparing with virgin aggregate mix. So, the rate of decreasing in stability value is small until 30% RAP then this rate becomes big after that (at 40%). For calcareous RAP, the percent of decreasing in stability values is 13.75%, 20%, 24.5%, 32.5% and 34.5% for 10%, 20%, 25%, 30% and 40% of RAP respectively. So, the rate of decreasing in stability value is small until 25% RAP then this rate becomes big after that (at 30% and 40%). Stability values of all used asphalt mixes satisfy the requirements of the specification limits.

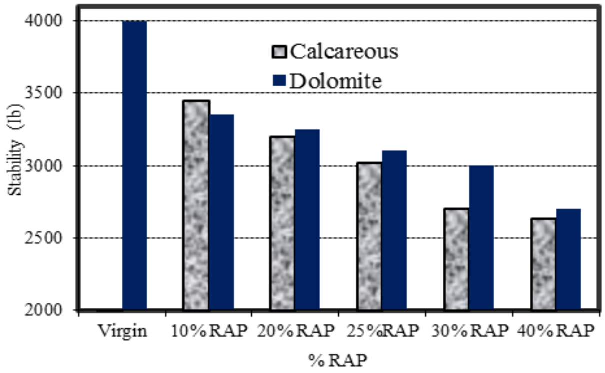

FIG.3: Influence of utilizing various percentages of RAP materials on the values of stability of the used asphalt mixes.

5.1.3. Results and analysis of mix density

Influence of utilizing various percentages of dolomite and calcareous RAP on the density values of asphalt mixes is shown in Figure 4. From this figure it can be noticed that, for dolomite and calcareous RAP, value of density decreases due to increasing of RAP percentage (inverse relationship). Also the percent of decreasing of density is 2.58% and 7.26% from zero to 40% of adding dolomite and calcareous RAP respectively. So the influence of utilizing various % of dolomite and calcareous RAP on the density values of the investigated asphalt mixes is too small.

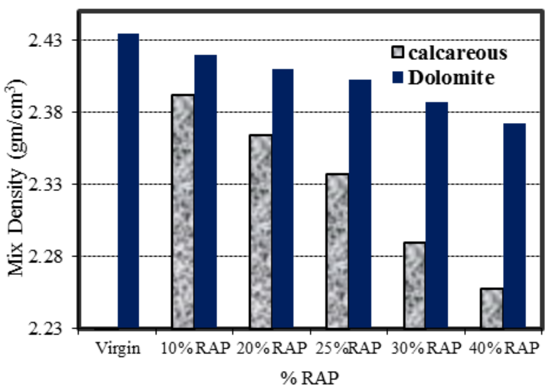

FIG. 4: Influence of utilizing various percentages of RAP materials on the values of density of the used asphalt mixes.

5.1.4. Results and analysis of mix flow

Figure 5 presents the influence of utilizing various % of dolomite and calcareous RAP on the values of flow of used asphalt mixes. From this figure it is obvious that, for dolomite and calcareous RAP, density value increases due to the increasing of RAP % (direct relationship). The specification limits of flow are the range (8 to 16 units). Every flow unit = 0.01 inch. Values of investigated asphalt mix flow for adding different percentages of dolomite and calcareous RAP are within the specification limits from zero to 30% and vice versa at 40% of adding dolomite and calcareous RAP. For dolomite, increasing values of flow units are 1.2, 1.5, 3.8 and 4.8 units for 10%, 20%, 25% and 30% of RAP. For calcareous, increasing values of flow units are 1, 2.1, 2.6, and 3 units for 10%, 20%, 25% and 30% of RAP.

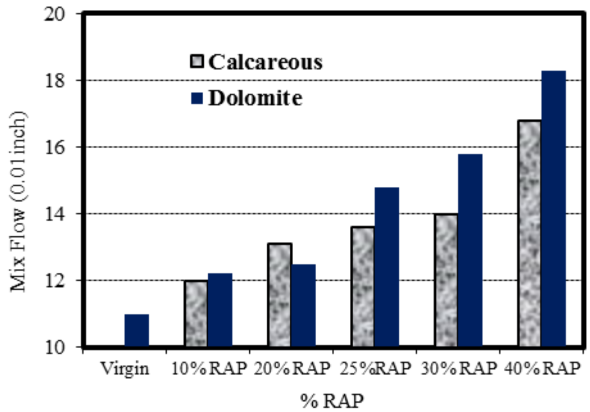

FIG.5: Influence of utilizing various percentages of RAP materials on the values of flow of used asphalt mixes.

5.1.5. Results and analysis of mix air voids

Figure 6 shows the influence of utilizing various percentages of dolomite and calcareous RAP on the air voids values of asphalt mixes. From this figure it can be noticed that, for dolomite and calcareous RAP, the value of air voids % decreases with increasing the percent of RAP. The presence of old asphalt in the aggregate pores, which minimizes the percent of air voids, may be the cause for the previous result. It is known that, the allowable range of air voids is (3% to 5%) of the total asphalt mix volume. For dolomite, for the range from zero to 30%

of adding RAP, values of % of air voids of investigated asphalt mixes are within the allowable range of air voids and vice versa at 40% of adding dolomite RAP. For calcareous, for the range from zero to 25% of adding RAP, values of % of air voids of investigated asphalt mixes are within the allowable range of air voids and vice versa at 30% and 40% of adding calcareous RAP. Values of investigated asphalt mix air voids at 40% dolomite RAP and 30% and 40% calcareous RAP are less than the specification limits (less than 3%). So, using these values of RAP will cause bleeding after construction especially in high temperature degrees regions. So, it is recommended that the acceptable RAP percent used in the asphalt mix must not exceed 25% and 30% of the total aggregate weight for calcareous and dolomite aggregate respectively to satisfy the specification limits of air voids % and to avoid bleeding.

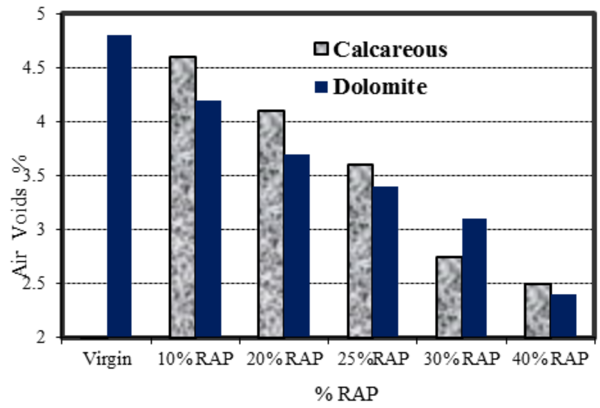

FIG. 6: Influence of utilizing various percentages of RAP materials on the values of air voids % of used asphalt mixes.

5.1.6. Results and analysis of voids in mineral aggregate (VMA)

Figure 7 presents the influence of utilizing various % of dolomite and calcareous RAP on the VMA values of asphalt mixes. From this figure it is obvious that, for dolomite and calcareous RAP, VMA value increases with the increasing of RAP % (direct relationship). The cause of this result is the presence of ineffective old asphalt prevents the new asphalt from entering deeply into the pores of aggregate. All values of VMA, for different percentages of dolomite and calcareous RAP, are within the allowable range of VMA (>14). The increasing increment in VMA values is 0.3, 0.65, 0.25, 0.6 and 2 for adding 10%, 20%, 25%, 30% and 40% of dolomite RAP respectively. So, the rate of increasing in VMA values is low until 30% of dolomite RAP after that the rate of increasing becomes high. The increment of increasing in VMA values is 0.5, 0.2, 0.5, 0.3 and 0.7 for adding 10%, 20%, 25%, 30% and 40% of calcareous RAP respectively. So, the rate of increasing in VMA values is low until 30% of calcareous RAP after that the rate of increasing becomes high.

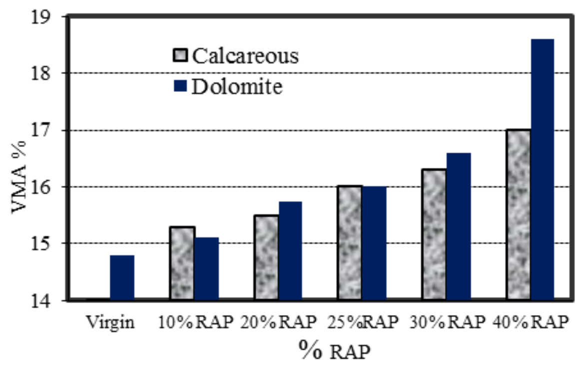

FIG. 7: Influence of utilizing various percentages of RAP materials on the values of VMA % of the used asphalt mixes.

5.2. Results and analysis of Indirect Tensile Strength (ITS) test

Asphalt mixes which used in ITS test were containing OAC resulted from Marshall test. Table 11 and Figure 8 present the influence of utilizing various % of dolomite and calcareous RAP on ITS values of asphalt mixes. From this figure it can be noticed that, for dolomite and calcareous RAP, as the percent of RAP increases the value of ITS decreases (inverse relationship). For dolomite RAP, the percent of decreasing of ITS values, comparing to the ITS value of the virgin asphalt mix at zero RAP, is 9.07%, 20.73%, 29.86%, 37.47% and 56.49% for 10%, 20%, 25%, 30% and 40% of added dolomite RAP respectively. It is clear that the rate of decreasing is small from zero until 30% of added of dolomite RAP then the rate of decreasing becomes high at 40%. Also, for calcareous RAP, the percent of decreasing of ITS values, comparing to the ITS value of the virgin asphalt mix at zero RAP, is 16.08%, 28.83%, 40.04%, 59.68% and 69.35% for 10%, 20%, 25%, 30% and 40% of added calcareous RAP respectively. It is clear the rate of decreasing is small from zero until 25% of added of calcareous RAP then the rate of decreasing becomes high at 30% and 40%.

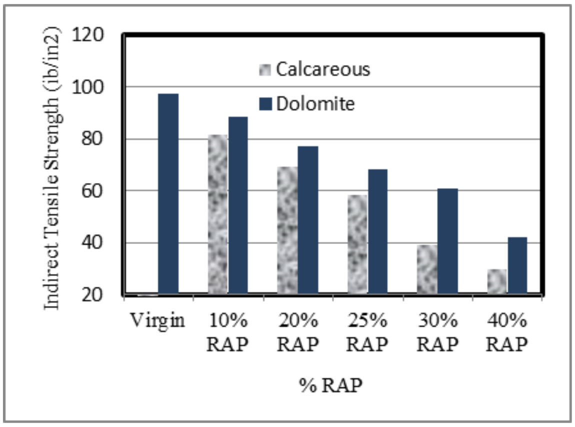

FIG. 8: Influence of utilizing various percentages of RAP materials on the values of indirect tensile strength (ITS) test of the used asphalt mixes.

Table 11: results of indirect tensile strength for the investigated asphalt mixes containing dolomite RAP and calcareous RAP

% RAP	Dolomite RAP		Calcareous RAP	
	OAC	Ib/in^2	OAC	Ib/in^2
Virgin	5	97.23	5	97.23
10% RAP	4.83	88.41	4.86	81.6
20% RAP	4.7	77.07	4.76	69.2
25% RAP	4.66	68.2	4.66	58.3
30% RAP	4.5	60.8	4.56	39.2
40% RAP	4.33	42.3	4.5	29.8

5.3. Loss of Stability (LOS) test results and analysis

The influence of utilizing various percentages of dolomite and calcareous RAP on LOS values of asphalt mixes is shown in Figure 9 and table 12. From this figure it can be noticed that, for dolomite and calcareous RAP, LOS % value increases due to increasing of RAP percentage (direct relationship). For dolomite RAP, the percent of increasing of LOS values, comparing to the LOS value of the virgin asphalt mix at zero RAP, is 19.69%, 30.7%, 39.37%, 44.09% and 86.61% for 10%, 20%, 25%, 30% and 40% of added dolomite RAP respectively. It is obvious that, for the range from zero to 30% of added dolomite RAP, increasing rate of the values of LOS is small then the rate of increasing becomes high at 40%. Also, for calcareous RAP, the percent of increasing of LOS values, comparing to the LOS value of the virgin asphalt mix at zero RAP, is 5.51%, 11.81%, 18.9%, 51.18% and 84.25% for 10%, 20%, 25%, 30% and 40% of added calcareous RAP respectively. It is obvious that, for the range from zero to 25% of added calcareous RAP, increasing rate of the values of LOS is small then the rate of increasing becomes high at 30% and 40%. All the values of LOS of the investigated asphalt mixes, for dolomite and calcareous RAP, are within the specification limits (less than 25%).

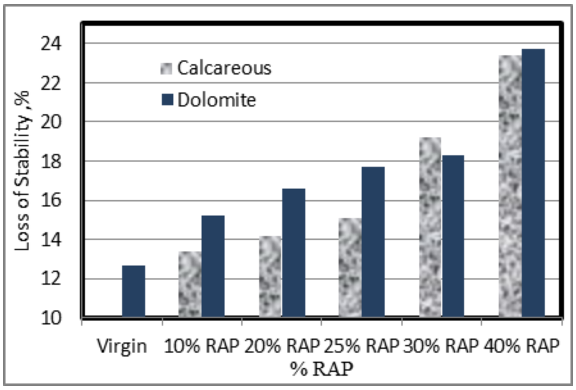

FIG: 9: Influence of utilizing various percentages of RAP materials on the values of LOS percentages of the used asphalt mixes.

Table 12: Results of loss of stability for the investigated asphalt mixes containing dolomite RAP and calcareous RAP

% RAP	Dolomite RAP			Calcareous RAP			Spec. limits
	Stab. 1/2 hour	Stab. 24 hour	Loss of stab.	Stab. 1/2 hour	Stab. 24 hour	Loss of stab.	
Virgin	4000	3490	12.7 %	4000	3490	12.7 %	≤ 25%
10% RAP	3350	2840	15.2 %	3450	2988	13.4 %	
20% RAP	3250	2710	16.6 %	3200	2746	14.2 %	
25% RAP	3100	2450	17.7 %	3020	2564	15.1 %	
30% RAP	3000	2490	18.3 %	2700	2181	19.2 %	
40% RAP	2700	2090	23.7 %	2630	2014	23.4 %	

5.4. Rigidity results and analysis

Figure 10 and table 11 present the influence of utilizing various % of dolomite and calcareous RAP on rigidity values of asphalt mixes. From this figure it can be noticed that, for dolomite and calcareous

RAP, as the percent of RAP increases the value of rigidity decreases (inverse relationship). For asphalt mixes containing dolomite RAP, the percent of decreasing in rigidity values is 24.49%, 28.49%, 42.39%, 47.78% and 59.42% for 10%, 20%, 25%, 30% and 40% of dolomite RAP respectively. Also, for asphalt mixes containing calcareous RAP, the percent of decreasing in rigidity values is 20.93%, 32.82%, 38.9.%, 46.96% and 56.95% for 10%, 20%, 25%, 30% and 40% of calcareous RAP respectively.

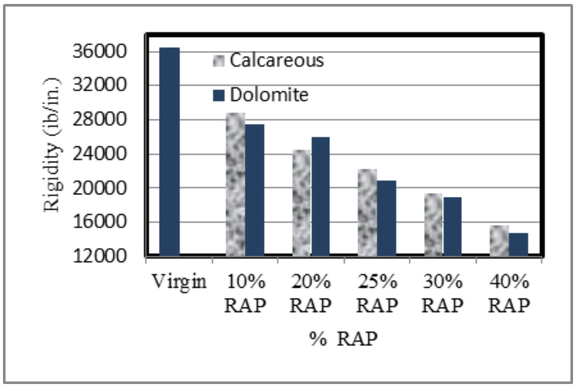

FIG. 10: Influence of utilizing various percentages of RAP materials on the rigidity values of the used asphalt mixes.

Table 13: Results of rigidity values for the investigated asphalt mixes containing dolomite RAP and calcareous RAP

`% RAP	Rigidity (ib./in)	
	Dolomite RAP	Calcareous RAP
Virgin	36363.63	36363.63
10% RAP	27459.02	28750
20% RAP	26000	24427.48
25% RAP	20945.94	22205.88
30% RAP	18987.34	19285.71
40% RAP	14754.09	15654.76

6. Conclusions

Conclusions of this study can be summarized as follows:

1. The best results of all studied parameters of investigated asphalt mixes satisfied at using 30% of dolomite RAP and at using 25% of calcareous RAP in asphalt mixes.
2. Increasing the percentage of added dolomite RAP or calcareous RAP decreases the values of OAC, absorbed asphalt, stability, density, air voids, rigidity and ITS (inverse relationship) and increases the values of flow, VMA and LOS (direct relationship).
3. Saving in used asphalt reached to 10% due to using 30% of dolomite RAP in asphalt mix but the saving in used asphalt reached to 6.8% due to using 25% of calcareous RAP in asphalt mix.

7. Recommendations

Recommendations of this study can be summarized as follows:

1. A 30% of dolomite RAP is appropriate to be used in flexible pavement, while the percentage of calcareous RAP is 25%.
2. Performing an economic study for using 30% of dolomite RAP and 25% of calcareous RAP in asphalt mixtures.
3. Constructing a field test containing 30% dolomite RAP and another one containing 25% of calcareous RAP in the asphalt layer to measure the actual performance under different traffic loading and realistic climatic conditions.
4. A future study is recommended taking into account many factors such as different types of RAP materials to investigate the performance of asphalt mixes containing RAP materials.

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