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Research paper



Evaluation of Optimum Content of Rice Husk Ash to Improve the Hot Asphalt Concrete Performance

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Abstract

Durability of asphalt pavements is related to choosing proper materials. Fillers as the smallest particles of stone materials, and one of the most important parts of asphalt mixtures, exert pivotal effects on the performance of asphalt mixtures, by filling empty spaces and because of their softness, surface features and chemical compounds. Rice husk ash is one of the waste products of burning rice husk in powerhouses that is accounted as biomass. Recently, a good many of investigations have shown that rice husk ash, as a high quality pozzolan, can be properly replaced of common aggregates. In this study rice husk ash was used as filler in hot mix asphalt, and the result mixtures' mechanical properties was compared with ordinary mixtures whose filler was stone powder. Asphalt mixture samples with two different aggregate graded, and 0, 25, 50, 75 and 100 percent of rice husk ash which were the substitution of stone powder content, were made and the effects of using rice husk ash on the moisture sensitivity, resilience modulus, rutting and dynamic creep of asphalt mixtures were investigated. The results demonstrated that increase of using rice husk ash as the replacement of prevalent fillers in hot mix asphalts, noticeably improves their performance; however, because of excessive stiffness created by rice husk ash, it's better to use it in optimized percentage. Accordingly, statistical analysis of the tests' results leads to presenting an optimized model for the content of Rice Husk Ash to be used in hot mix asphalt. Finally, Rice Husk Ash content were suggested 26% for graded number 4 and 48% for graded number 5 as replacements for stone powder filler.

Keywords: Hot Mix Asphalt, Rice Husk Ash, Biomass, Moisture Sensitivity, Rutting, Dynamic Creep

1. Introduction

Nowadays, various kinds of asphalt mixtures, are widely used in construction of pavements, because of good performance and serviceability, soft and comfortable driving and high endurance and durability. [1] In fact, researchers are aiming to provide more economic, durable, smooth and safe roads which have enough strength against predicted transportation loads. [2] Asphalt mixtures are formed out of three parts which are filler, asphalt binder and aggregates. In order to increase the bound between aggregates, the mastic resulted from mixing filler and asphalt binder, fills the spaces between aggregates. [3] Filler, as the fine-grained part, exerts pivotal role on mechanical properties and chemical behaviors of asphalt mixtures and is effective in fastening the materials. Mineral fillers are added to asphalt mixtures for two purposes, a part of natural filler which is smaller than binder film thickness, is mixed with asphalt binder and makes a primer which causes improving asphalt mixtures' stiffness. Particles greater than binder film thickness operate like natural aggregates and help bound between stone particles. [4] Moreover, fillers are different in graded, particles' shapes, and amount of empty spaces, mineral material combinations and physical-chemical properties. Therefore, their effects on hot mix asphalts characteristics are different. [5] filler's role in asphalt mixtures is significant, for the reason that the interaction between filler and asphalt binder can influence asphalt mixtures' properties. Additionally, fillers by having large surface areas, cause increase in asphalt binders' absorptions which alters asphalt mixtures' performance. It is reported that type and amount of filler can affect asphalt mixture's properties such as resistance against deformation, fatigue behavior and moisture sensitivity. [6]

It is observed that in recent years, the development of mining industry and heavy usage of raw materials put serious limitations on natural resources. Enormous volume of exploitations and the shortage of raw materials have resulted in production and recycling waste materials. In addition, one of the major concerns of numerous countries is how to manage the increasing amounts of waste materials, since the locations of these huge volumes' burials near many cities are super saturated. [7] Moreover, the construction and maintenance of roads require plenty amount of aggregates for base, subbase and pavement layers. [8] On the other hand, nowadays, because of shortage and limitation of existing resources, there is a huge demand for waste materials in highway industry. Therefore, replacements of various ordinary aggregate parts used in asphalt mixtures with waste materials, is an efficient approach for cutting down the costs and also improving pavement properties. Besides, researches claim that burning biofuels does not provoke the increase of greenhouse effects which are results of releasing carbon dioxide in the atmosphere [9-11] Biomasses approximately provide 10 percent of the world's energy for producing heat and electricity. [12] Rice husk ash is a biomass ash which comes from burning rice husk in powerhouses and furnaces. Currently, rice husk ash, because of having proper characteristics, is widely used in concrete production industry, and has the potential of being used as filler in pavement industry, too.

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2. Research history

In 2 recent decays, in order to reduce the consumption of new resources and handle with the environmental problems resulted from new construction, researchers in the field of engineering are trying to find ways for recycling, modifying, and reusing waste materials in new productions. [14] a wide range of investigations have been conducted in order to substitute ordinary mineral fillers (stone powder) with other materials which have better performance and the resulted pavements are more flexible and economic. [15-18]
As it said before, one kind of those materials is biomass ashes. The results of investigations demonstrate that most of biomass ashes have properties which are useful in asphalt concretes' performance. [19] Sargin et al. in 2013 conducted an investigation about using rice husk ash as filler in asphalt concrete. limestone powder was replaced with rice husk ash resulted from combustion in 700 degree of centigrade in chamber, with content of 5 % in 25, 50, 75 and 100 % portions, and by comparing the results, the optimized portion of rice husk ash for replacement was defined. Results demonstrated that samples which consist of filler with 50 % limestone and 50% rice husk ash (filler consist of 2.5% rice husk ash and 2.5% limestone powder), has the best stability in Marshall assessment test. Moreover, it becomes clear that where rice husk ash exists abundantly, it can be used in place of limestone powder in asphalt mixtures as mineral filler. [20] In another investigation in 2014 rice husk ash was used as a substitution for a part of cement filler in got mix asphalts. In this investigation, asphalt mixture samples were made with rice husk ash filler as substitutions for cement filler in 0, 5, 7.5, 12.5, 15, 17.5,20, 22.5, 25 percent and the optimum asphalt content were determined. Results showed that Marshall Parameters for samples with 10% rice husk ash and 90% Portland cement and 5.5% optimized binder, are matched with code requirements. [21] In 2016, Alhadbi used rice husk ash as filler in hot mix asphalt and compared the results with samples made with cement as filler. The results released that the strength of samples made with rice husk ash grew in 65 percent in comparison with control samples. Additionally, moisture sensitivity and aging tests made clear that rice husk ash filler develops the mechanical characteristics as well as increases the aging spans and durability of asphalt mixtures. [22] In another survey conducted in 2017 the effects of rice husk ash and slag, as filler in asphalt mixtures were assessed and their performance was compared with stone powder filler mixtures. In this investigation asphalt mixture samples with mentioned fillers were made and Marshall Test was done. The results displayed that mixtures made with rice husk ash filler have more Marshall Stability than mixtures made with slag filler and stone powder filler. [23]
In another study the appropriateness of rice husk ash (RHA) and fly ash in hot mix asphalts as a substitution for common fillers was investigated. The results pointed out that using RHA in asphalt mixtures by 4 percent, the resistance against moisture sensitivity of the rice husk ash in comparison with other investigated fillers and also the best Marshall stability in this percent belongs to asphalt mixture samples made with RHA. [24]

3. Research importance

Regarding to enormous volume usage of stone materials which are majorly provided by mountain and river resources, utilizing recycled and waste materials in civil, industrial … activities seems economically and environmentally important. Therefore, in this study, rice husk ash is replaced a part of the filler material (stone powder) in hot mix asphalt and the effects are examined carefully.

4. Research method

In this study, after providing stone materials, asphalt binder and rice husk ash, asphalt mixture samples were made with different combinations. Considering the fact that, in Iran, still Marshall Test is conducted for assessment of asphalt concrete properties, and with employing this approach, after determination the optimum asphalt content, other samples were made with the optimum asphalt content of each combination. After that, modulus of resistance, moisture sensitivity, rutting and dynamic creep tests were conducted on different combinations of rice husk ash and the results were analyzed.

4.1. Materials and the corresponding tests

Materials used for making h consist of three parts of aggregates (coarse and fine grain), asphalt binder and filler. By conducting specified tests for aggregates and asphalt binder, the properties of aggregates, asphalt binder and used filler are determined the following will be discussed.

4.1.1. Aggregates' properties and corresponding graded

For making asphalt mixture samples used in this study, broken aggregates of the mine in the north of Iran were used. The graded characteristics are presented in table (1). Also, the stone materials' properties are showed in table (2)

Table 1: Graded number 4 and 5 of hot mix asphalts based on Iran standards.

Average passing percentage		**Sieve size (mm)**
graded number 5	graded number 4	mm
----	100	19
100	95	12.5
95	----	9.5
70	59	4.75
49.5	43	2.36
15	13	0.3
6	6	0.075

Table 2: stone material properties

description	**Test standard**		**Allowable range according to 234 publication of Iran**		**2Test results**
	ASTM	AASHTO	Wearing course	Binder course	
Ultimate abrasion according to Los Angeles (%)	C131	T96	25	30	**23**
Ultimate long flat aggregates (%)	D4791	--	15	15	**0.7**
Fracture percentage of aggregates on sieve number 4 in two degrees	D5821	--	90	80	**%91**
Weight loss percentage against sodium Sulphur (coarse grain)	C88	T104	8	8	**0.12**
Weight loss percentage against sodium Sulphur (fine grain)	C88	T104	12	12	**0.15**
Ultimate content of water absorption of coarse grain	C127	T85	2.5	2.5	**2.1**
Ultimate content of water absorption of fine grain	C128	T84	2.5	2.8	**2.3**

4.1.2. Asphalt binder and its properties

The utilized asphalt binder in this study was pure binder 60-70 which was provided from Ghiran Pakhsh Setareh Iranian and its physical properties are represent in table (3)

4.1.3. Filler

In this investigation two kinds of filler were used in preparing asphalt mixtures. Stone powder filler which is gained by breaking and grinding stone particles and was used as control filler, and rice husk ash which was the substitution of a portion of control filler or the whole content of it. Afterward, the performance of asphalt mixtures with these two fillers was examined and the results were compared. The specific weights of the utilized fillers in this study are depicted in table (4). In the following, rice husk ash properties and its preparation method are briefly described.

Table 3: Physical properties of asphalt binder

Test	standard	unit	Test results
Specific weight in 25℃	ASTM D70	gr/cm^3	1.019
Penetration degree	ASTM D5	℃	67
Flash point	ASTM D92	℃	310
ductility in 25℃	ASTM D113	cm	More than 100
Softness point	ASTM D36	℃	49.8

Table 4: specific weight of used fillers

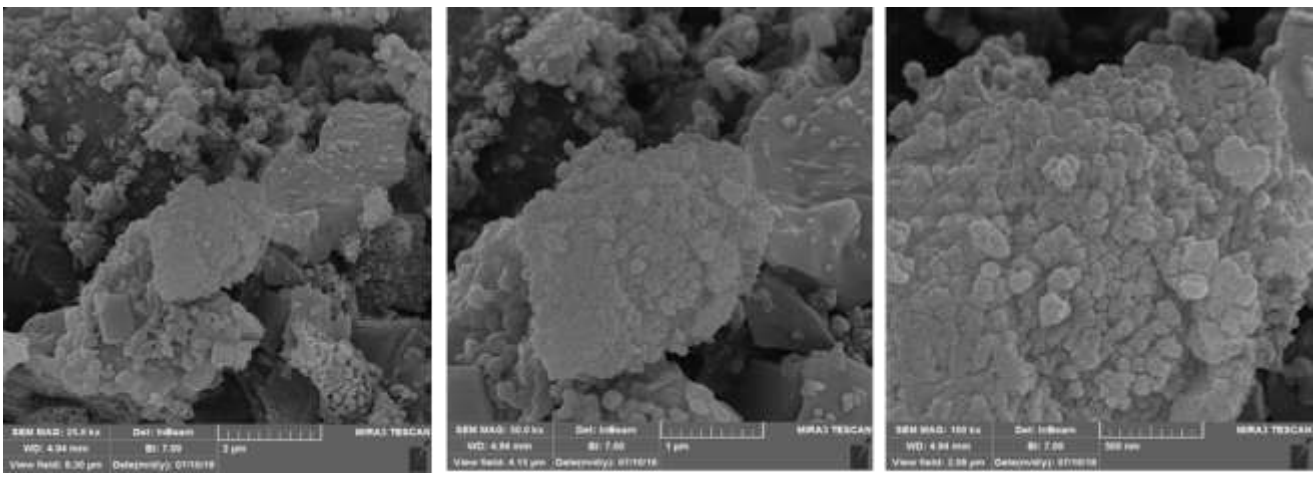
Kind of filler	Rice husk ash	Stone powder
Specific weight (gr/cm^3)	2.09	2.628

4.1.3.1 Rice Husk Ash

Rice husk is a waste product which is gained during rice production. From rice hulls, during production procedure, in peeling off and whitening instruments, 78% of total weight, rice, some broken rice and bran and finally 22% in the form of rice husk are remained. By burning rice husk, approximately 75% of its weight run out in the form of volatile organic materials and only 25 percent remains in the form of ash. This ash, is known as Rice Husk Ash (RHA) [25]
Rice hulls has two internal and external Husk. The internal husk which is extremely thin, is called bran and is useful for edible usage. The external husk which is the rice husk or hulls husk is a bit thicker and is not proper for eating. Rice husk, generally because of lacking of cellulose and sugar materials, is not advised even for cattle's' feeding. [26]
Regarding to abundant rice fields and huge content of rice production in the North of Iran, enormous content of rice husk is produced in Iran, without proper usage. Furthermore, taking out this material from environment, faces various obstacles. On the other hand, RHA is a valuable product which is accounted as a raw material with different potentials. Currently, its major application is burning it in power houses as fuel. These process leads to huge content of RHA which is often deposited or released to rivers and causes environmental pollutions. Pozzolanic activity of RHA is closely dependent to burning conditions, temperatures and burning durations. [27] In this study rice husk was taken form a local rice factory in North of Iran. At first, rice husk was burned in an open space and then in order to decarbonate the material, it was burned for the second time, in a specific furnace with 700 centigrade degrees for 90 minutes. The achieved ash was grinded for one hour so as to get the particular graded (smaller than 0.075 mm). The chemical characteristics of the achieved RHA from XRF test is represented in table 5. Figure (1) also displays the Field Emission Scanning Electron Microscope (FE-SEM) image.

Table 5: XRF test results for defining chemical properties of Rice Husk Ash

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	K_2O	TiO_2	MnO	P_2O_5	5LOI
percent	88	0.48	3.834	0.727	0.166	0.511	1.618	0.031	0.136	0.392	4.105



(A) **(B)** **(C)**

Fig. 1: FE-SEM RHA image in scale A) 2 Micrometer B) 1 Micrometer C) 500 Nano meter

4.2. Making samples, mixture design and conducting tests

4.2.1 Making samples

In this study, Marshall Method according to ASTM-D1559 standard, was used for the mixture design. The samples were made on the basis of middle range of continuous graded number 4 and 5 of hot mix asphalts of Iran's standard publication number 234, with 4, 4.5, 5, 5.5, 6, 6.5 percent asphalt binder and by 0, 25, 50, 75 and 100 percent substitutions of RHA for stone powder as filler, for heavy traffic. 180 asphalt mixture samples (6 various asphalt binder percent), 3 samples for each binder percent, 5 combinations of different percent of fillers and two graded (10 in total combinations) were prepared and Marshall stability, flow, specific weight and Rice tests were conducted in order to determine the optimum asphalt content for 10 particular combinations. In the next step, by having the optimized percent of asphalt binder for 10 mixtures and with the graded used in the previous step, asphalt mixture samples were made in order to conduct the resilient modulus, rutting, moisture sensitivity and dynamic creep tests.

4.2.2 Moisture sensitivity test

Moisture sensitivity, causes drop in adhesion, and leads to noticeably undesirable effects on asphalt mixture's strength. Moreover, it can cause premature damages like rutting, stripping ... [28] Tensile strength test is conducted in order to determine the tensile strength of asphalt mixtures. Tensile strength of asphalt mixtures is because of conjunction strength of asphalt binder (the strength caused by the bound between aggregates' surface and asphalt binder). Tensile strength is calculated by the ultimate load that a sample can tolerate before rupture. The effect of water on the decline in asphalt mixtures' strength is one of the major concerns in mixture design, which is assessed under the title of moisture sensitivity. [29-30] AASHTO T283 is one of the most common methods for determination of asphalt mixtures' moisture sensitivity. This test is conducted on compact samples with empty space percent 7 ± 0.5. The minimum number of samples for each mixture is 6. Half of the samples should be treated and kept in standard conditions, in a way that samples are kept under vacuum circumstance in order to reach 55 to 80 percent saturation level. The vacuum saturated samples are kept in freezer in -18 centigrade degree for 16 hours and then they are kept in water bath in 60 centigrade degree for 24 hours. Finally, samples which were kept under standard circumstance and the other samples are kept in constant 25 centigrade degree temperature. Indirect tensile strength test with constant rate of loading (50mm/min) is conducted on both of the two groups of samples and the required loads for breaking samples are measured. After reaching the required loads for breaking samples, Indirect Tensile Strength (ITS) is calculated according to equation (1).

$$\text{ITS} = \frac{2000P}{\pi.D.t} \quad (1)$$

In which:

ITS: tensile strength (kPa)
P: maximum load (N)
D: sample dimension (mm)
t: sample thickness (mm)
The resistance of samples against moisture is shown with TSR in percent which is calculated according to equation (2). The ITS value in equation (2) is the average value of dry and saturated samples. TRS should be 75% and when it increases it means higher resistance against moisture. [31]

$$\text{TSR} = \frac{ITS_{dry}}{ITS_{saturated}} \quad (2)$$

4.2.3 Resilience module test

Resilience module of asphalt mixtures which is measured with indirect tensile method according to ASTM D4123, is one of the most common methods for assessing the elastic properties of materials. Resilience module which is one of the important mechanical properties of asphalt mixtures is the elastic modulus in cyclic loading with very small strain. Generally, asphalt mixtures' behavior in road pavement systems is viscoelastic and is a function of loading rate, its intensity and temperature. If the load is small in comparison with strength of material, and it repeats in long periods of time, deformation is almost completely reversible in each load cycle. [32] The resilience module test was conducted by using UTM 5 device with these characteristics: half sinus load shape, loading duration 0.1 second, relaxing time 0.9 second, the preloading number 50 cycles, pulse number 5 cycles. The test was done on each sample in a tension level (30 percent of tensile strength in similar temperature and age condition). The test was repeated twice for each sample and the averages of results was used in calculations. The Poisson ratio was taken 0.35 and the tests were conducted in constant temperature of 25 degree of centigrade.

4.2.4 Wheel track test

Rutting in asphalt pavements is noticed with long concavity deformations under wheels paths and causes bump of near marginal parts. Rutting shortens the service age of pavements and by effecting vehicles may cause serious threaten for road users. This phenomenon can reduce the drainage capacity of pavements. Deepening the tracks leads to a wide range of obstacles in the safety of roads. When the track's depth is 5 millimeters, it holds water and as a result the potential of Hydroplaning occurrence will increase. Therefore, studying this phenomenon is important for asphalt mixtures. [33, 34] In order to investigate the asphalt mixtures' function against rutting, wheel track test was conducted on asphalt mixture samples by the wheel track device of the university of Science and Technology in Tehran. For this test, 3 samples of each mixture, at first, were placed in 50 degrees of centigrade. Then, cylinder samples were placed in the device and loaded by 2 wheels which rotated around their centers with 690 kPa compression. The loading frequency for each sample is 1 Hertz and the temperature is 50 ℃. Totally, samples were loaded by 8000 cycles and the depths of created tracks were measured. The average of the depths of tracks of three samples was accounted as the track depth of each mixture.

4.2.5 Dynamic creep test

Dynamic creep test, by determining the cumulative strain of asphalt mixture samples, makes clear their performance against rutting. The most important output of dynamic creep test is depicting diagrams of the cumulative strains against number of load cycles which are consisted of three parts. In the first part, permanent displacements are cumulated which are highly ascending. In the second part, the increase of cumulative strains occurs with mild constant slope. And in the third part the slope and displacements continuously increase again. The flow number which is gained from dynamic creep test, is the cycles' number in the third part. [35] Vitzak for the first time showed that the flow number gained from dynamic creep test is in direct relation with asphalt concrete rutting strength. [36] In this investigation the creep test was conducted by UTM 5 device. The applied load in 40 ℃ was considered in the form of rectangular wave, by which 500 milliseconds loading and 1500 milliseconds relaxation according to Australia standards were applied. [37] The contact tension was adjusted to 20 kPa and the deviation tension 450 kPa. Two criteria were considered for finishing the test. The maximum strain and maximum number of loading which was defined 30000 micro and 40000 cycles respectively.

5. Test results

5.1. Marshall test results and determination of optimum asphalt content

After considering Marshall test results (table 6), the average percent related to the best specific weight, Marshall stability and empty space percent results were taken and observed in VMA, VFA and Flow in order to be sure of placing in the range determined by the code. The achieved asphalt binder percent was defined as the optimized binder percent corresponding to the same sample which has a predefined content of RHA (0, 25, 50, 75 or 100 percent). Table (9) shows the results of optimized asphalt binder percent for the 4 and 5 graded. Because of more binder absorption of RHA in comparison with stone powder, the optimum asphalt content of samples with RHA are higher. It can also be seen in table (7). It can be observed from the results that in 4 and 5 graded, the optimized asphalt binder of graded number 5 is more than graded number 4. Its reason is that the smaller particles of graded number 5 leads to more absorption of binder. By optimized asphalt binder percent from table (7), new samples with previous graded were made for each RHA percent and the resilient module, moisture sensitivity, rutting and dynamic creep tests were conducted.

Table 6: A part of Marshall Test's results and its parameters (samples are made with 4.5 percent binder and grading number 4)

G_{mb}(gr/cm^3)	V_a(%)	VMA(%)	VFA(%)	Stability(kg)	Flow(mm)	RHA percent
2.324	3.89	14.08	72.37	1165	2.40	0
2.315	3.90	13.54	71.20	1296	2.45	25
2.308	4.11	13.36	69.24	1328	2.60	50
2.284	4.67	13.82	66.21	1332	2.90	75
2.258	5.68	14.36	60.45	1274	3.00	100

Table 7: he optimum asphalt content for asphalt mixture samples

Samples' name	RHA percent (%)	Optimized binder percent (%)	Graded number
R0-4	0	5.03	4
R25-4	25	5.11	4
R50-4	50	5.22	4
R75-4	75	5.28	4
R100-4	100	5.37	4
R0-5	0	5.25	5
R25-5	25	5.32	5
R50-5	50	5.43	5
R75-5	75	5.51	5
R100-5	100	5.62	5

5.2. Moisture sensitivity results

Considering the Marshall test's results and achieving optimized percent of asphalt binder for each mixture, some samples were made for assessment the moisture sensitivity of asphalt mixtures by conducting indirect tensile test on samples according to AASHTO T283 standard. TSR which is an effective index for moisture sensitivity assessment is a result of dividing tensile strength of saturated samples by dry samples. According to standard publication of Iran number 234, TSR resulted from AASHTO T283 should not be less than 75 percent. The total results of indirect tensile test are represented in table (8) and (9). As we can see, by increasing RHA, tensile strengths of asphalt mixtures increase for either wet or dry samples in comparison with control samples. Additionally, by analyzing the results of TSR ratios it can be seen that increasing RHA percent leads to growing TSR and better strength than control samples, which means the positive influence of RHA on resistance against damages stem from moisture. The reason for this positive effect can be explained by previous investigations. RHA as an artificial pozzolan, by having more than 90 percent active Silica, reacts severely with binder which causes improvement of Rheologic properties of binder, besides the hydrogen bound between binder and SiO_2 , which results in more adhesion between binder and aggregates and therefore better performance against moisture. Table (8) and (9) and also figures (2) and (3) display the fact that increasing RHA by 25, 50, 75 and 100 leads to increase of TSR by 7.7, 13, 18.1, and 22.8 percent for graded number 4 in comparison with control samples. These results are 4.1, 7.2, 10.9 and 12.6 for graded number 5.

Table 8: Indirect tensile results for graded number 4

Asphalt mixture sample's name	ITS saturated (kPa)	ITS dry (kPa)	TSR (percent)
R0-4	582	769	75.68
R25-4	611	749.5	81.52
R50-4	665	777.5	85.53
R75-4	801	896	89.39
R100-4	882.5	949.5	92.94

Table 9: Indirect tensile results for graded number 5

Asphalt mixture sample's name	ITS saturated (kPa)	ITS dry (kPa)	TSR (percent)
R0-5	540	690.5	78.20
R25-5	596.5	733	81.38
R50-5	670	799	83.85
R75-5	747.5	862	86.72
R100-5	805	914.5	88.02

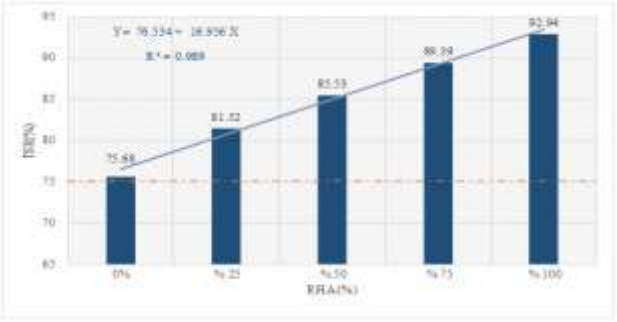


Fig.2: TSR ratio for samples made with graded number4

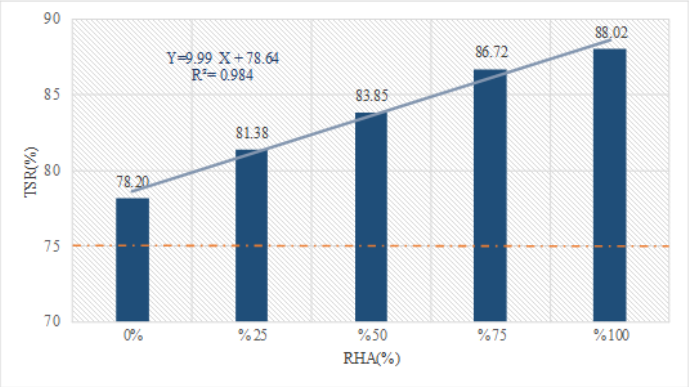


Fig.3: TSR ratio for samples made with graded number 5

5.3. Resilience module test results

Resilience module test results are depicted in figure (4) and (5). The results demonstrate that resilience modules of asphalt mixture samples have increased noticeably and this phenomenon causes stiffness growing of the mixtures. This increase for the graded number 4 is 54% and for graded number 5 is 117 % more than control samples. This amount of stiffness growing demonstrates that increase in RHA content Rice adhesion between binder and materials considerably, withstanding the fact that more RHA causes more empty space and therefore inverse relation with resilience module. The increase of resilience module has a direct relation with asphalt concrete layer coefficient for designing the asphalt layer thickness and as the modulus increase this ratio goes higher and the thickness increases. However, too much increase of this module may cause hardening the asphalt concrete layer, and being brittle increases the probability of cracking. So, in the code the resilience module of asphalt concrete layer which is consist of binder course and wearing course according to ASTM D-4123 is determined to be less than 31500 kg/cm^2 or 3089.14 MPa. In figure (4) and (5) if we enter 3089.14 MPa in achieved regression relations, the maximum percent of RHA for having the allowable elasticity module will be attained. This value for graded number 4 and 5 are 26% and 48% respectively.

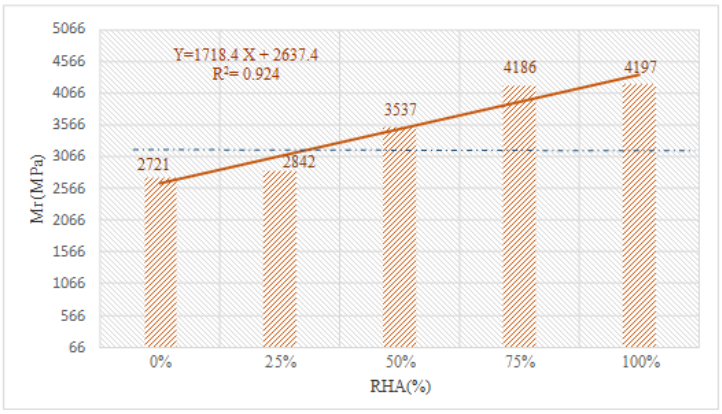


Fig. 4: Resilience module for samples made with aggregates' graded number 4

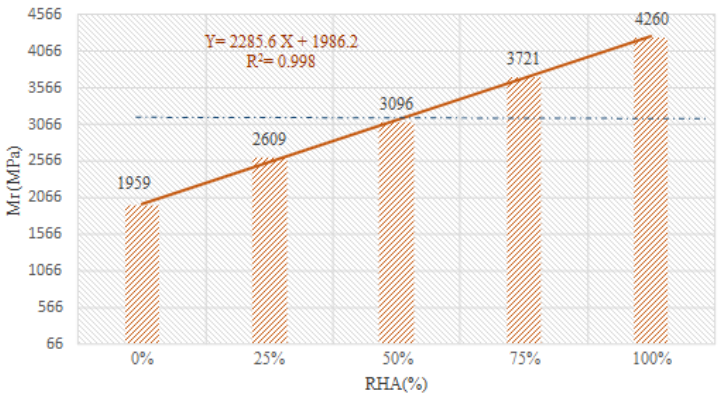


Fig.5: Resilience module for samples made with aggregates' graded number 5

5.4. Wheel track test results

In figure (6) and (7) the results of rutting test can be seen. It is clear from the diagrams that samples made with RHA have more resistance against rutting and with increasing RHA percent, the asphalt mixture samples. Inasmuch as rutting is considerably influenced by stiffness, the more stiffness, the more resistance against permanent deformation. Samples made with more additional material, are stiffer and as a result more resistant against rutting.

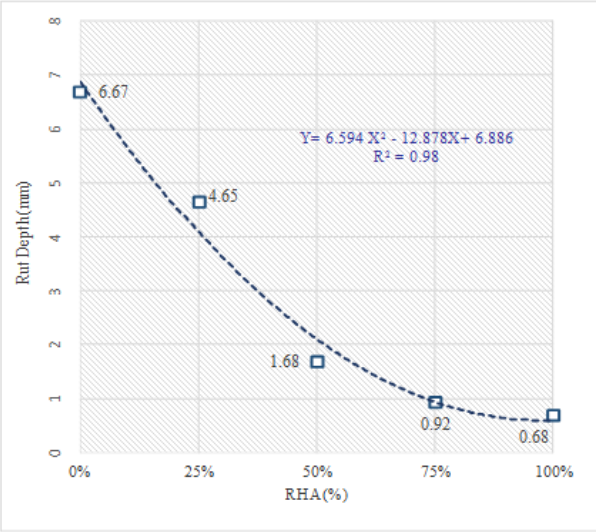


Fig. 6: Rutting test result for samples made with aggregates graded number 4

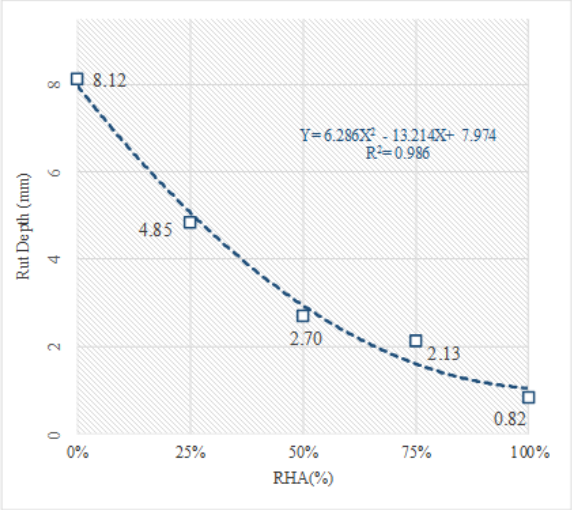


Fig.7: Rutting test result for samples made with aggregates graded number 5

5.5. Dynamic creep test

As mentioned before flow number against number of loading cycles in cumulative strain curve resulted from dynamic creep test, is the number of load cycles in third part. Figure (8) is a portion of this test's result. Figure (9) and (10) show the alteration of flow numbers of asphalt mixture samples with regard to various percent of RHA. As we can see by increasing RHA, the corresponding flow number goes up. Therefore, higher flow number, reduces the potential of samples' rutting which causes less track depth in wheel track test. It is obvious in figure (6) and (9) and also (7) and (10). In addition, the figure (11) shows that the results of the Wheel Track and Dynamic Creep tests have a good correlation coefficients.

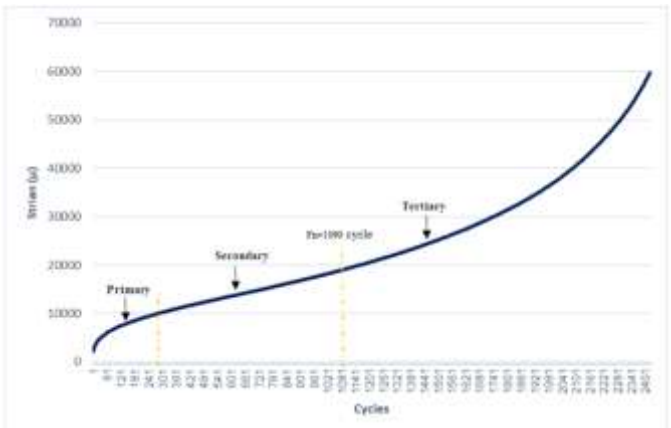


Fig. 8: Dynamic creep test result for samples made with aggregates graded number 4 and 25% RHA (R25-4)

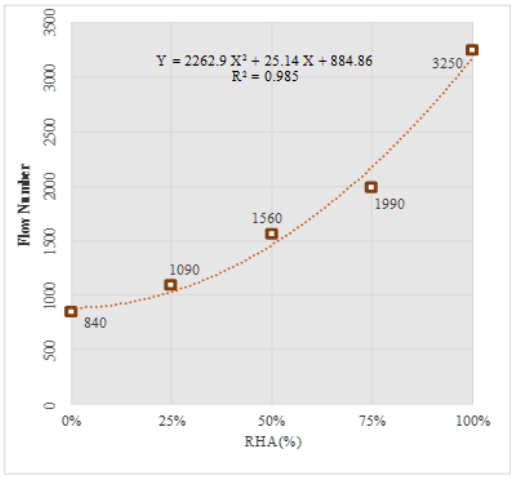


Fig. 9: Alteration of Flow number in samples made with graded number 4 and various RHA percent

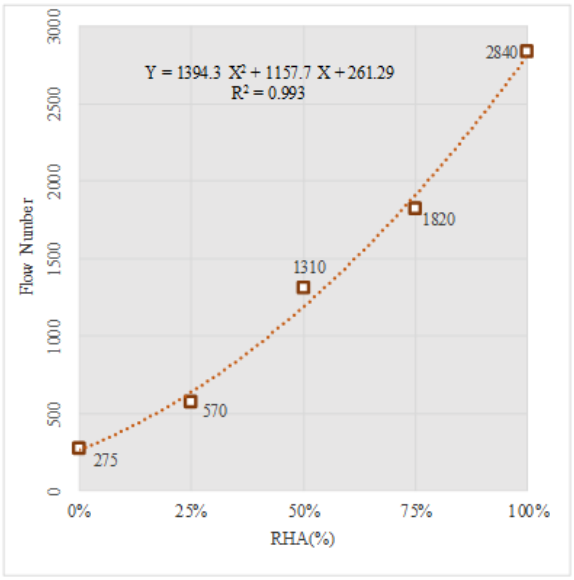


Fig. 10: Alteration of Flow number in samples made with graded number 5 and various RHA percent

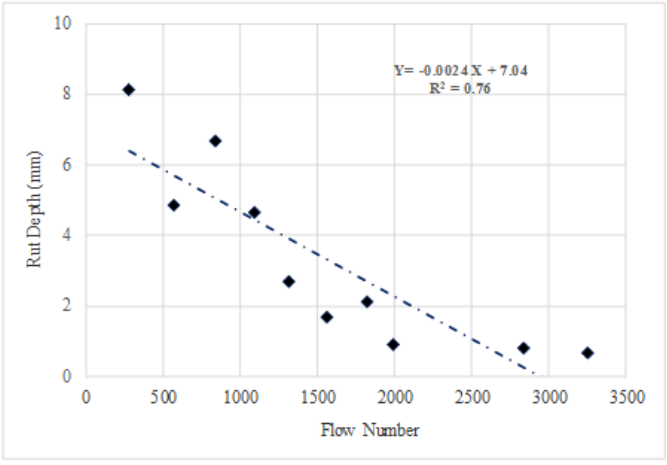


Fig. 11: Relationship between Rutting Depth and Flow Number in this research for graded number 4 and 5

6. Analyzing results and determination optimized RHA Content

Considering the conducted tests, all the results of RHA samples for all the tests, except resilience module test, are in the code allowable ranges. By analyzing the results of resilience module test, it becomes clear that too much RHA makes the sample too stiff. Therefore, the maximum content of RHA in asphalt mixtures for having allowable properties for graded number 4 and 5 were determined. The results of moisture sensitivity, rutting and dynamic creep tests also demonstrated that more usage of RHA in place of stone powder can improve asphalt mixture samples' performance and there is no limit for its content. Marshall Test results pointed out that the stability of all samples made with RHA are more than the code's requirements. It can be concluded from what mentioned before that the optimized RHA content for substitution of stone powder and passing all requirements of the code is the content gained in resilience module test. As a result of this study it can be said that for

graded number 4 and 5 the optimized content of RHA in place of stone powder is 26% and 48% respectively.

7. Conclusion

In this study, at first, samples were made with 0, 25, 50,75 and 100 percent RHA as a substitution for stone powder for graded number 4 and 5 and with 4, 4.5, 5, 5.5, 6, 6.5 binder percent. Marshall Test was conducted and Marshall Parameters were attained. Then, according to results of specific weight, flow, Marshall stability, VMA, VFA and V_a, the particular optimum asphalt content for each RHA percent was gained. After that, new samples with optimized binder percent and graded used in the previous step, were made. 10 kinds of asphalt mixture samples were prepared: five samples for graded number 4 and five samples for graded number 5. Moisture sensitivity, rutting, resilience module and dynamic creep tests were conducted on these samples. The results are mentioned in the following

1. By increasing RHA content, tensile strengths of asphalt mixtures, in comparison with control samples, either for saturated or dry conditions increase.
2. For samples made with graded number 4, with increasing RHA by 25, 50, 75 and 100 percent, the TSR amount grows 7.7, 13, 18.1, 22,8 percent respectively. These values are 4.1, 7,2,10.9 and 12.6 for graded number 5
3. By increasing RHA content in asphalt mixture samples, the resilience modules of samples, has greatly increased. This increase toward control samples is 54% for graded number 4 and 117% for graded number 5.
4. The results make clear that samples made with RHA have higher resistance against rutting and by increasing RHA the track depth reduces.
5. The dynamic creep test results confirm the results of rutting test. According to these results, the alteration of flow number goes up by increasing RHA content which demonstrates more resistance of samples made with RHA against rutting.

The optimum RHA content, with considering the code's requirements and limitations, are determined 26% and 48% for graded number 4 and 5 respectively.

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