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Structural Evaluation of Cold Recycling Reclaimed Asphalt Pavement (RAP) Blends

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Abstract

The technique of cold recycling of asphalt pavement materials for road construction is widely used in the world. Different types of locally available stabilizing additives and/or agents were used to find the most suitable one from the point of view of strength, economy and environment. Cubic molds of (10) cm is used in the laboratory to prepare samples of the stabilized rap materials. The effect of curing mode (effect of water absorption) was studied from strength point of view. Increasing bricks sand in the stabilized RAP materials increase the compression strength because of filling the spaces. A brick sand increasing reduces the absorption in case of cement stabilizing while with lime increases the absorption. Dynamic modulus of elasticity decreases with bricks sand increasing. Cement ratio more than 5% alone or more than 3% with lime is recommended to use, lime stabilizing ratio not exceed 10%.

Keywords: cold recycling, reclaimed asphalt pavement (RAP), crushed bricks sand, compression waves velocity and dynamic modulus of elasticity.

تقييم إنشائي لخلطات التبليط الإسفلتي المستصلح المدور باردا

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الخلاصة :

إن تقنية إعادة تدوير التبليط الإسفلتي بالأسلوب البارد في إنشاء الطرق واسعة الاستخدام عالميا ويعتبر التبليط الإسفلتي المدور أكثر المواد المدورة استخداما في العالم.استخدمت مواد تثبيت ومواد مضافة مختلفة لإيجاد الملائم منها

من وجهة النظر الإنشائية والاقتصادية والبيئية. قوالب مكعبه بابعاد 10 سم استعملت، و تم الآخذ بنظر الاعتبار طريقه الانضاج (تأثير امتصاص الماء) بالهواء او بالماء. ان أضافه رمل الطابوق المكسر عند تثبيت ماده التبليط المدورة بالاسمنت يزيد من مقاومة الكسر للنماذج على العكس من النوره كذالك زيادة رمل الطابوق فيمواد الطرق المدورة والمثبتة يزيد من مقاومه الانضغاط بسبب ملئ الفراغات كما تبين ان زيادة رمل الطابوق يقلل من الامتصاص في حاله التثبيت بالسمنت بينما يزيد من الامتصاص في حاله النوره. معامل المرونه الحركي يقل بزيادة رمل الطابوق. نسبة السمنت الموصى باستعمالها اعلى من 5 % ومع النوره اعلى من 3 %،نسبة النوره المثبتة لاتتجاوز 10 %.

1. Introduction

Flexible pavements are exposed to excessive traffic load repetitions and heavy axle loads, severe environmental conditions, and poor maintenance activities which lead to structural and functional failure in the pavement. The maintenance and reconstruction costs are increasing rapidly due to the extensive volume of the deteriorated road pavement worldwide, on the other hand the reconstruction of distressed pavement using recycling techniques is evolving as the best practice to reconstruct or improve pavement serviceability level and structural capacity with low cost. Reclaimed Asphalt Pavement (RAP) is an existing asphalt mixture that has been pulverized, usually by milling, and is used like an aggregate in recycled asphalt pavement.[1]

RAP produced from surface courses (compared to binder courses), is usually of a higher quality because of higher quality aggregates used in the original construction [2].

[3]The benefits of RAP as the volume of heavy good vehicles are multiplying year by year. This has led to various distresses in the pavement. The aging of bitumen binder is yet another problem causing deterioration of pavements. The method commonly preferred to protect the road system is overlaying the distressed pavements with virgin courses. But this leads to thickening of pavement layers, depletion of natural ingredients, and use of non-renewable resources and emissions of harmful gases.

Accumulated RAP materials out of maintained roads pollute the environment as well as bricks factories residue of bricks, the benefit of using this waste materials as aggregate (coarse and fine aggregate) economy because it is not priced and free as compared with another materials that used in construction of roads layers.

Brick exposed to high degrees of temperature during construction it have high compressive strength.

Cold recycling advantages include :conservation of non-renewable resources**,** energy conservation compared to other reconstruction methods, eliminates the disposal problems inherent in conventional methods, problems with existing aggregate gradation and/or asphalt binder can be corrected withproper selection of new granular materials and stabilizing additives. [4]

[5] An investigation in the stabilizing RAP with hydrated lime and the effect of adding limestone dust to hydrated lime stabilized RAP, the finding of this investigation had showed that, using hydrated lime alone as a stabilizing material was not successful because the

mixture had very weak strength and failed to hold the cubes intact after opening even if the percentage had been increased up to 5%. moreover at equal percentage of the hydrated lime to limestone dust, there was an increase in both the density and unconfined compressive strength with the increase in hydrated lime percentage (linear relationship) while for the compressive wave velocity and dynamic modulus of elasticity there was a reduction in the increase after 4% hydrated lime- limestone dust percentage added. For all percentages of limestone dust to lime, there was a reduction after 4% of lime in modulus. The best proportion is equally proportioned lime to limestone dust from compressive strength point of view. At this investigate on the adding of Portland cement to hydrated lime and limestone dust in stabilizing RAP materials appeared that the addition of ordinary Portland cement to RAP materials stabilized with hydrated lime and limestone dust did not improve the strength characteristics.

[6]An investigation to achieve concrete of higher strength using crushed brick as aggregate and studying the mechanical properties. It was found that higher strength concrete (fc= 4500 to 6600 psi) with brick aggregate is achievable whose strength is much higher than the parent uncrushed brick.

2. Materials

The materials that used in the study consisted of reclaimed asphalt materials, stabilizers and crushed bricks sand as additive.

2.1 Reclaimed asphalt pavement (RAP):

used as aggregate material, it's crushed from surface course (5 cm) depth by milling machine from Al-Sibba'aySt. at Al-Mansour district in Baghdad city which had heavy cracks**, Figure(1)** shows the RAP. Resistance to Abrasion of RAP Coarse Aggregate in Los Angeles machine and the test result 24% it is carried out according to **ASTM** [7]and $CBR_{100\%}$ value is 19.24 %, withaccordance to **ASTM** [8] **.**

2.2 Crushed bricks sand:

Waste materials used from milling crushed bricks till passing from sieve 4.75 mm, Sieve analysis is carried out according to **ASTM** [9]. It can be classified according to **AASHTO** [10] as A-1b coarse sand and also according to **ASTM** [11] (USCS), as (SP) poorly graded sand.Liquid Limit (L.L. %) 44.3 and it is not plastic matter.

2.3 three different local types of stabilizers are used,

Namely; hydrated lime, Portland cement and combination of them.

2.3.1 Lime:

Hydrated lime from Al-Noora lime plant of southern cement state company of Ministry of Industry and Minerals is used. Fineness% (according to **ASTM** [12]) is 8 and the chemical composition consisting of 92.5% $Ca(OH)_2$ and 5.5% residue.

2.3.2 Portland cement:

sulphate resistant cement was obtained from local market named (Al-Jisser), Fineness % (according to ASTM C 184)96.8 and Compressive strength (MPa) (**ASTM** [13]) 24.12 at 7days.

Fig .(1): The RAP Material.

3. Experimental work

Experimental work consisting of samples preparation and testing program as following:

3.1 Samples preparation:

By choosing some percentages of crushed bricks sand to the RAP materials with some trials of stabilizers percentages to obtain indicates to the structural behavior of samples. Cubic molds of (10) cm is used in the laboratory to prepare samples of the stabilized rap materials according to Iraqi standard specification No. 52/1970[14]**.**The mixing water was taken the minimum percentage that gives workability to the mixture by selecting the optimum amount of mixing water (about 100% to binder) from strength point of view. The effect of curing mode (effect of water absorption) was studied from strength point of view and the **Table (1)** showing the testing program of the prepared samples for the designate mixtures.

Table .(1) Testing Program

Air cured samples	Water cured samples
1- stabilized with hydrated lime	
Rap + 4% hydrated lime + 8% crushed bricks sand	Rap + 5.5% hydrated lime + 5.5% crushed bricks sand
Rap + 5.5% hydrated lime + 11.5 % crushed bricks sand	Rap + 5.5% hydrated lime + 11.5 % crushed bricks sand
Rap + 8.5% hydrated lime + 17 % crushed bricks sand	Rap + 10.5% hydrated lime + 11.5% crushed bricks sand
Rap +10.5% hydrated lime + 21 % crushed bricks	Rap + 10.5% hydrated lime + 21 % crushed bricks
Rap + 12.5% hydrated lime + 12.5 % crushed bricks sand	
2-stabilized with Portland cement	
(All samples cured in water).	Rap + 5.5 % crushed bricks sand + 5.5 % Portland cement
	Rap + 8.5 % crushed bricks sand + 5.5 % Portland cement
	Rap + 11.5 % crushed bricks sand + 5.5 % Portland cement
	Rap + 5.5 % crushed bricks sand + 7 % Portland cement
	Rap + 8.5 % crushed bricks sand + 7 % Portland cement
	Rap + 11.5 % crushed bricks sand + 7 % Portland cement
3-stabilized with hydrated lime and Portland cement	
Rap + 5.5% hydrated lime + 5.5 % crushed bricks sand +3% cement	Rap + 5.5% hydrated lime + 5.5 % crushed bricks sand +3% cement
Rap + 5.5% hydrated lime + 5.5 % crushed bricks sand +5.5% cement	Rap + 5.5% hydrated lime + 5.5 % crushed bricks sand +5.5% cement
Rap + 5.5% hydrated lime + 11.5 % crushed bricks sand +3% cement	Rap + 5.5% hydrated lime + 11.5 % crushed bricks sand +3% cement
Rap + 5.5% hydrated lime + 11.5 % crushed bricks sand +5.5% cement	Rap + 5.5% hydrated lime + 11.5 % crushed bricks sand +5.5% cement

3.2 Experimental Tests:

3.2.1 Strength testing:

It include both of compression wave velocity and unconfined compressive strength.

3.2.1.1 Compression waves velocity:

It is achieved by ultrasonic pulse velocity device to determine dynamic modulus of elasticity according to BS 1881[15]with the dynamic Poisson's ratio (υ equal to 0.2 for lime treated soils as mentioned by NCHRP 1-37A[16]. This test is carried out according to ASTM C597[17] for all samples immediately before compression testing and for dry samples.

3.2.1.2 Unconfined compressive strength:

Prepare three for cubes for every sample mixture for air cured and water cured cubes. Tested under compression machine applies the load at a rate of (1.25 KN / second) with an accuracy of 0.01 KN. **Figure (2)** shows the compression testing machine (by Al-mustansiriya university/college of engineering/ civil engineering department/materials laboratory) and **Figures (3) And (4)** show the testing samples.

Fig .(2): compression testing machine.

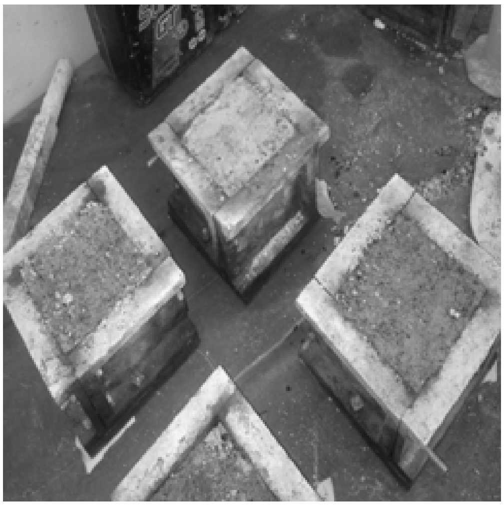

Fig .(3) Prepared samples

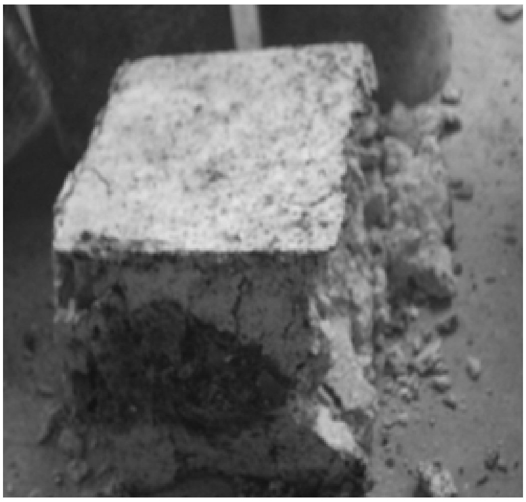

Fig .(4): compression tested sample

3.2.2 The Testing Of Water Absorption:

The samples are weighted after final setting and extraction. The sample out of the mold, and then they were immersed into water tank for four days. Then, the samples are extracted from water and left to dry for 15 minutes, after that the samples are weighted then the water absorption percentage was calculated. **Figure (5)** shows the immersed samples.

1- immersing samples **2- compression tested soaked samples**

Fig .(5) Soaked Samples.

4. Testing Results and Analysis:

Figure (6) shows the compression strength of samples of RAP treated with bricks sand and stabilized with hydrated lime and cured in air. There is an increase in strength with the increase of bricks sand because of filling the voids, while with the increase of hydrated lime increases strength to a specific limit then a reduction occurs with more increasing of hydrated lime content. These results do not comply with SCRB 2003[18]limits for base course layer (2.5 MPa) and higher percentages of hydrated lime and bricks sand are needed to improve the strength. The density of samples also increases slowly with increase of bricks sand because the weight of RAP is heavier than low percent of sand, as shown in **Figure (7**).The samples immersed (or cured) in water, as shown in **Table (2)** have lower compressive strength values, as compared with the same mixtures which cured in air, and the reduction is increased with increasing of bricks sand. These results do not comply with SCRB 2003 limits for base course layer stabilized materials. But some of the results which reached to 1MPa may use as sub base or sub grade layer. Increasing of hydrated lime content reduces the absorption of water.

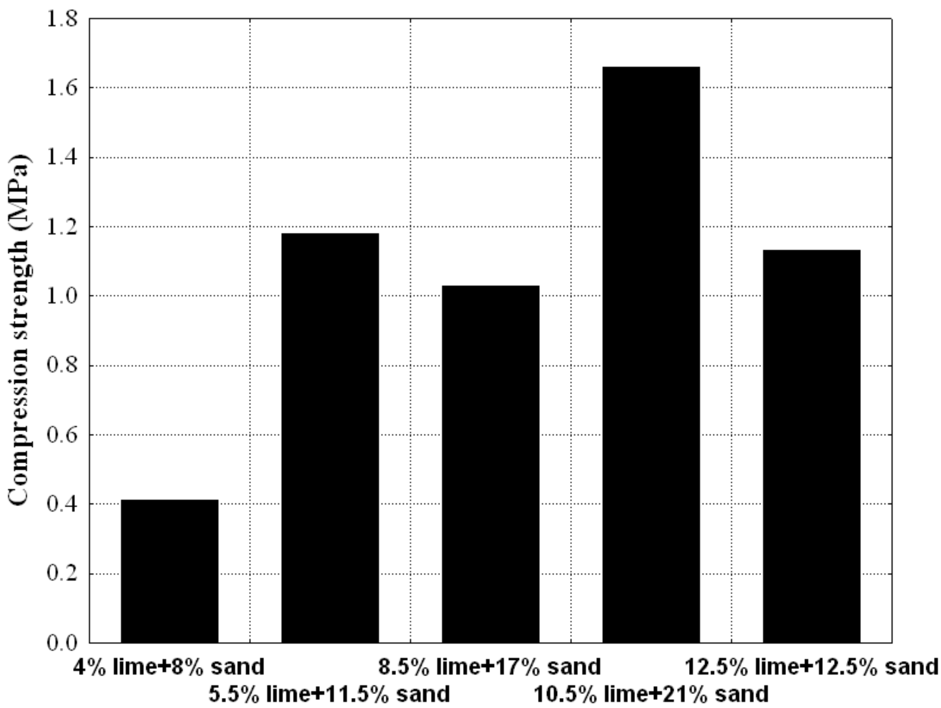

Fig .(6): The compression strength of RAP materials plus bricks sand treated with different percentages of hydrated lime and tested after 7 of curing in air.

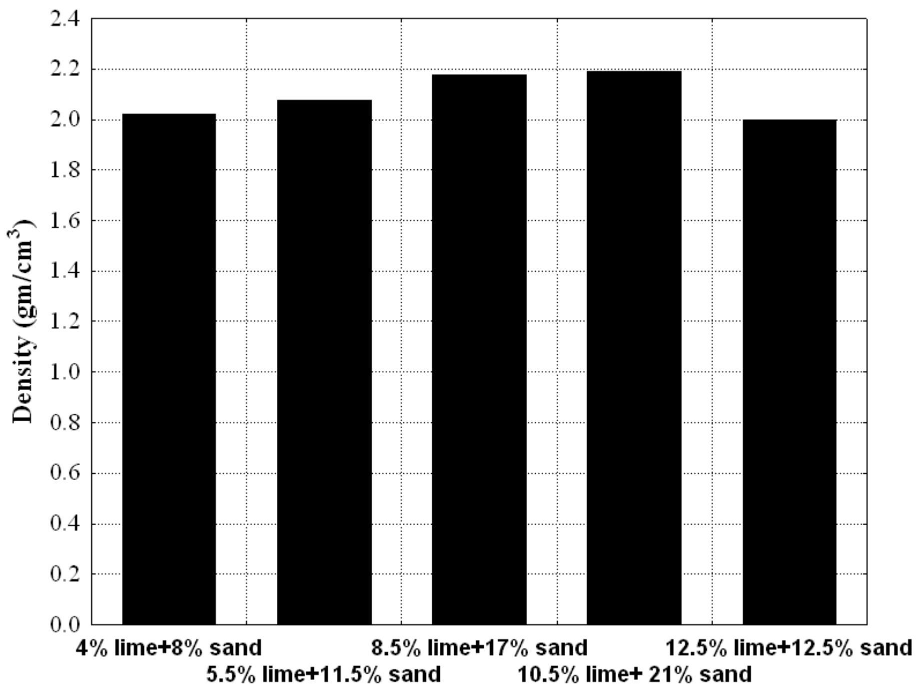

Fig .(7): The density of RAP materials plus bricks sand treated with different percentages of hydrated lime and tested after 7 of curing in air

Table .(2) The compression strength and absorption of water for samples immersed in water.

Water absorption %	**7th day compression strength (MPa)**	**Crushed bricks sand %**	**Hydrated lime %**
6.65	1	5.5	5.5
4.95	0.28	11.5	5.5
3.33	0.92	11.5	10.5
2.75	1.2	21	10.5

Figures (8) and (9) are prepared to show the compression strength hand density of samples of RAP treated with crushed bricks sand and stabilized with Portland cement (there is weak bond less than 5% of Portland cement). The compressive strength at 7th day water cured samples increases with increasing crushed bricks sand content linearly and these results explain that there is a possibility of selecting either increasing bricks sand content or increasing Portland cement content to obtain acceptable strength satisfying the Iraqi limits for cement treated base course. While the density decrease with the increase of bricks sand.

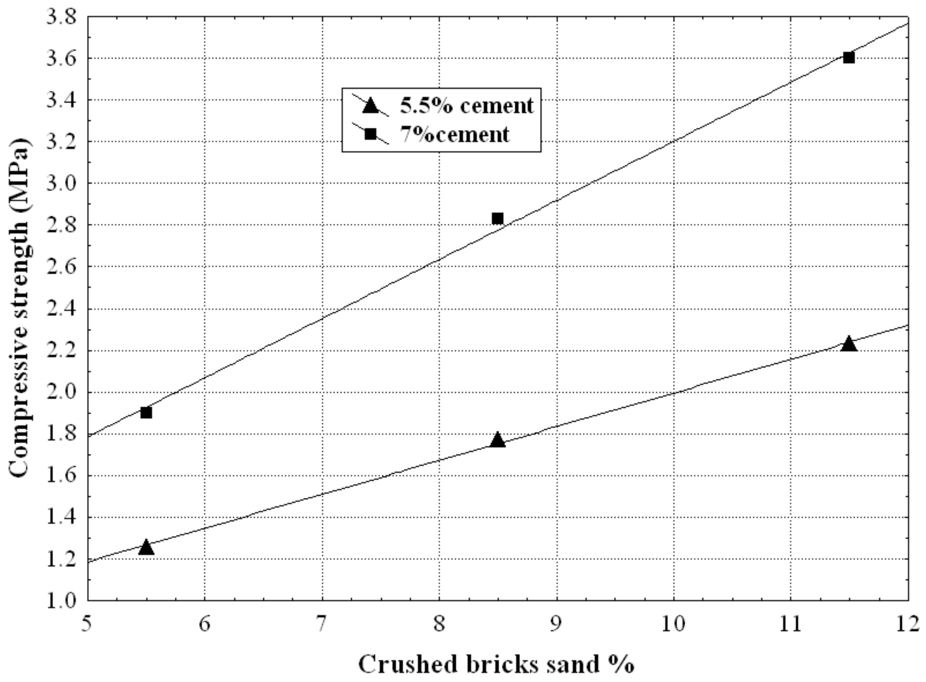

Fig .(8): The compression strength of RAP materials plus bricks sand treated with two percentages of Portland cement and tested after 7 of curing in water.

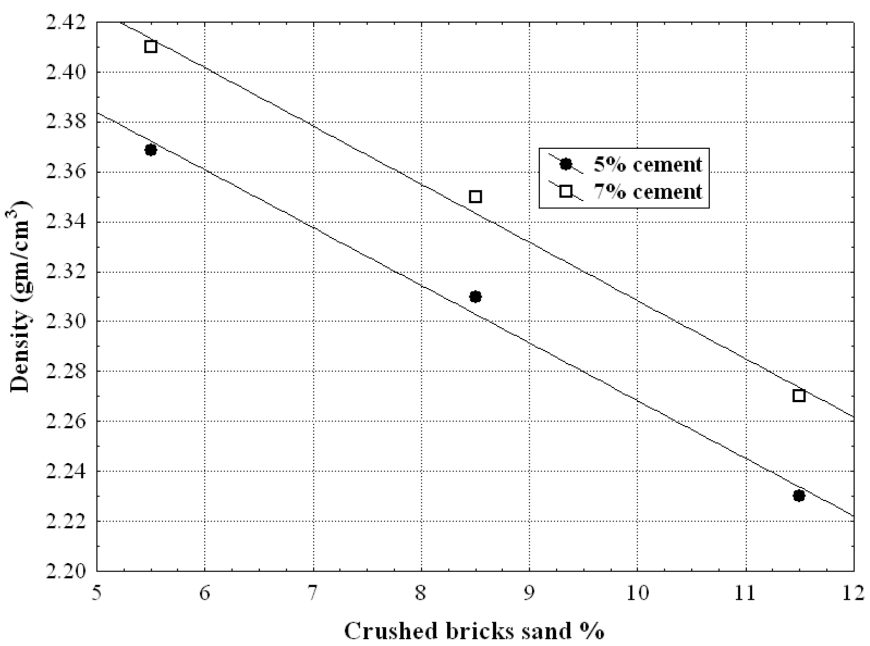

Fig .(9) The density of RAP materials plus bricks sand treated with two percentages of Portland cement and tested after 7 of curing in water.

The absorption of water decreases clearly with increase of bricks sand and Portland cement linearly because of absorption of cement, as shown in **Figure (10).** As a comparison between using lime and cement; cement make the strength increasing with its increasing not like lime reach to specific limit.

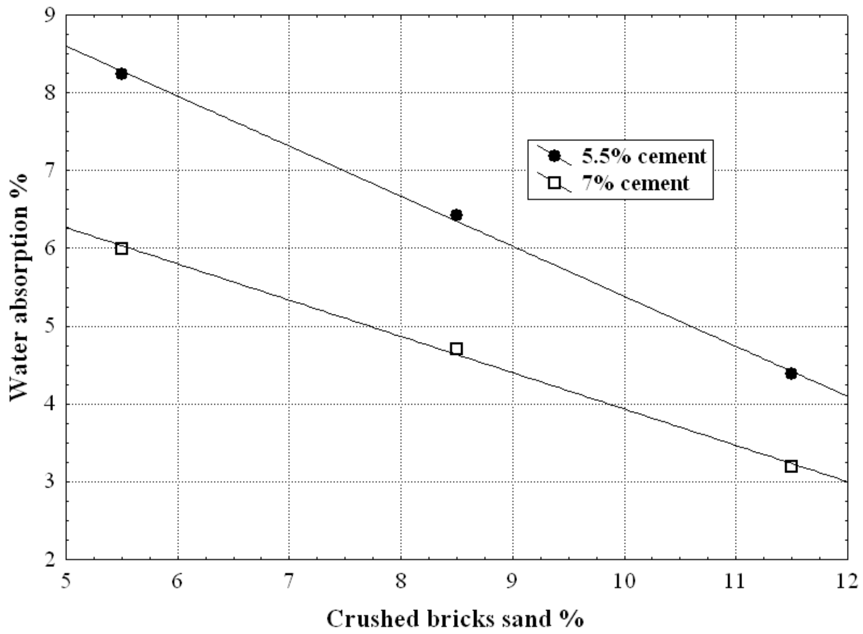

Fig .(10): The water absorption of RAP materials plus bricks sand treated with two percentages of Portland cement and tested after 7 of curing in water.

Figures (11) and (12) show the compression strength and density of rap samples treated with bricks sand and stabilized with Portland cement and hydrated lime for 7 days air curing. Compression strength increases with the increase of both bricks sand and Portland cement content. While, the samples density is not really being affected with increasing of bricks sand in proportion to Portland cement content, it increases with the increase of Portland cement content.

The compression strength of soaked samples increases with increasing of Portland cement content. As shown in **Figure (13),** the comparison of compressive strength between air and water cured samples revealed that the loss in strength between the two curing methods is related to the increase of bricks sand. Compressive strength of immersed samples does not comply with SCRB 2003 specifications for base course due to the action of lime under humidity. **Figure (14)** is prepared to show the effect of bricks sand and Portland cement alternating contents on the samples water absorption; water absorption increases with increasing of crushed bricks sand content, while increasing Portland cement content reduces the absorption because cement need to water to reaction and consume it.

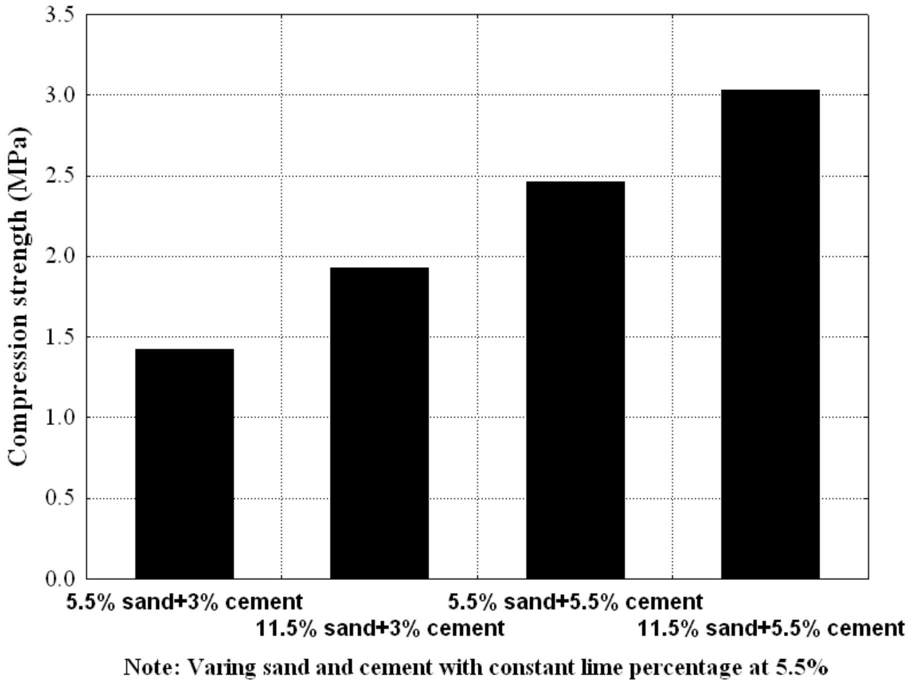

Fig .(11) The compressive strength of RAP materials plus bricks sand treated with different percentages of Portland cement with 5.5% hydrated lime and tested after 7 of curing in air.

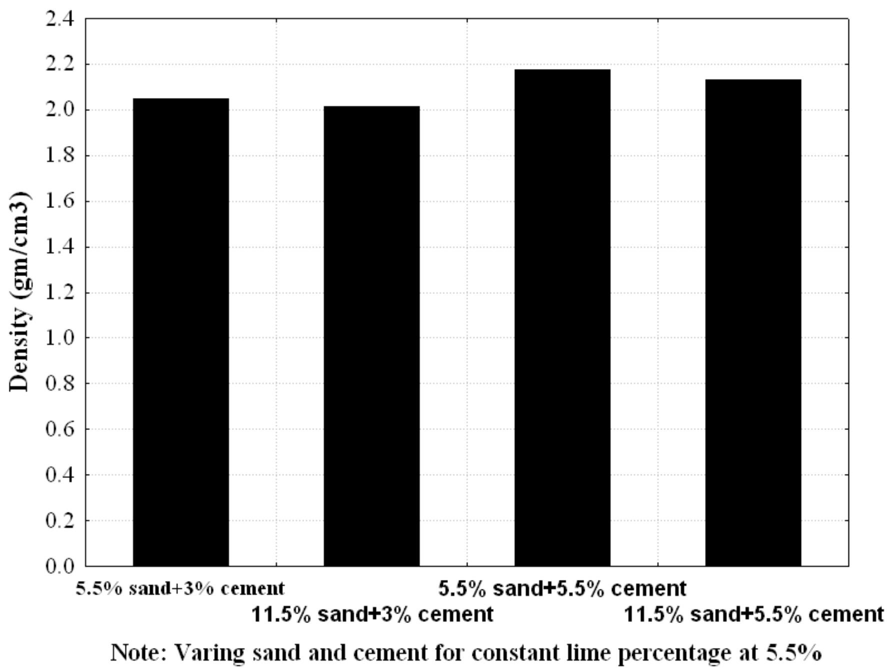

Fig .(12) The density of RAP materials plus bricks sand treated with different percentages of Portland cement and 5.5% hydrated lime and tested after 7 of curing in air.

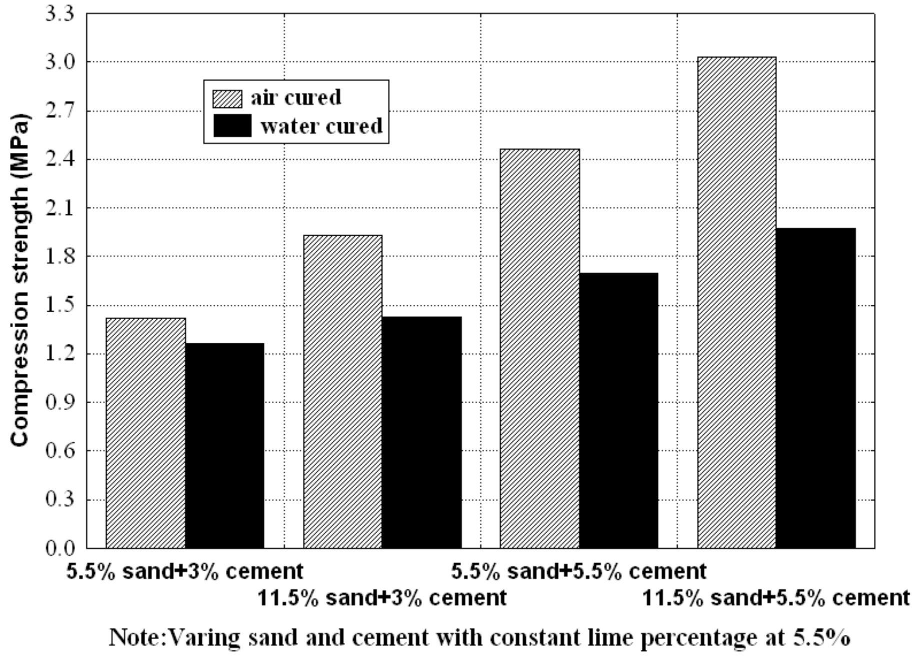

Fig .(13) The compression strength of RAP materials plus bricks sand treated with different percentages of Portland cement and 5.5% hydrated lime and tested after 7 of curing in air and in water.

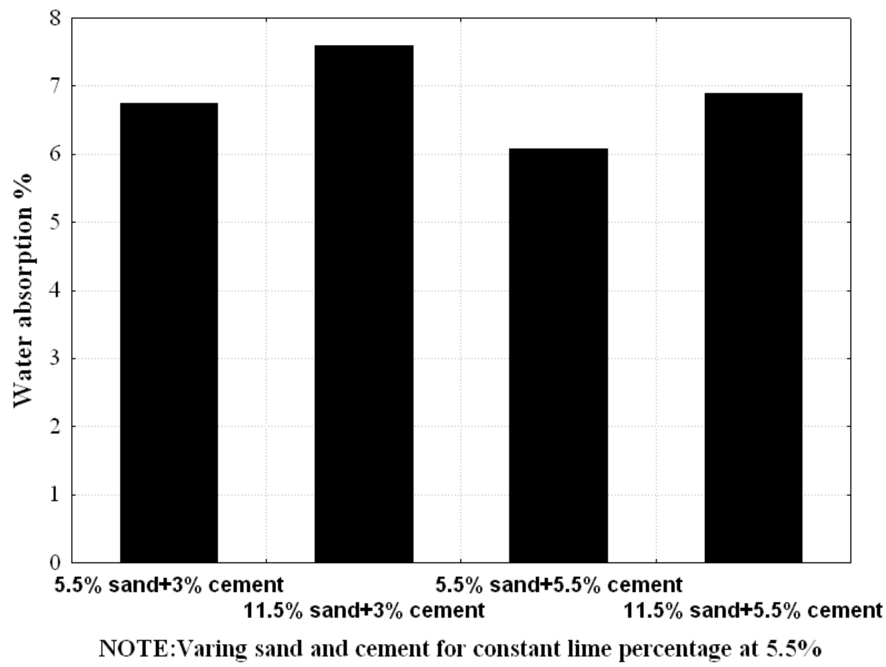

Fig .(14) The water absorption of RAP materials plus bricks sand treated with different percentages of Portland cement and 5.5% hydrated lime and tested after 7 of curing in water.

The ultrasonic pulse velocity used to measure the dynamic modulus of elasticity later (it is one of the elements of the structural design requests) it is non-destructive test. Is measured for the samples of RAP treated with bricks sand and stabilized with hydrated lime and cured in air increases with increase of bricks sand and hydrated lime. **Figure (15)** shows the ultrasonic pulse velocity of tested samples.

The increase in pulse velocity is little which effects on dynamic modulus of elasticity values according to BS 1881, 203. **Figure (16)** shows the dynamic modulus with Poisson's ratio of 0.2 for lime treated materials.

Figure (17) is prepared to show the effect of adding crushed bricks sand to treat the RAP (that stabilized with Portland cement)on dynamic modulus of elasticity for the samples; it is showing that; the modulus is decreasing with increasing of bricks sand because low rigidity of sand and density.

There is contrary relationship between dynamic modulus and compression stress for samples that treated with cement.

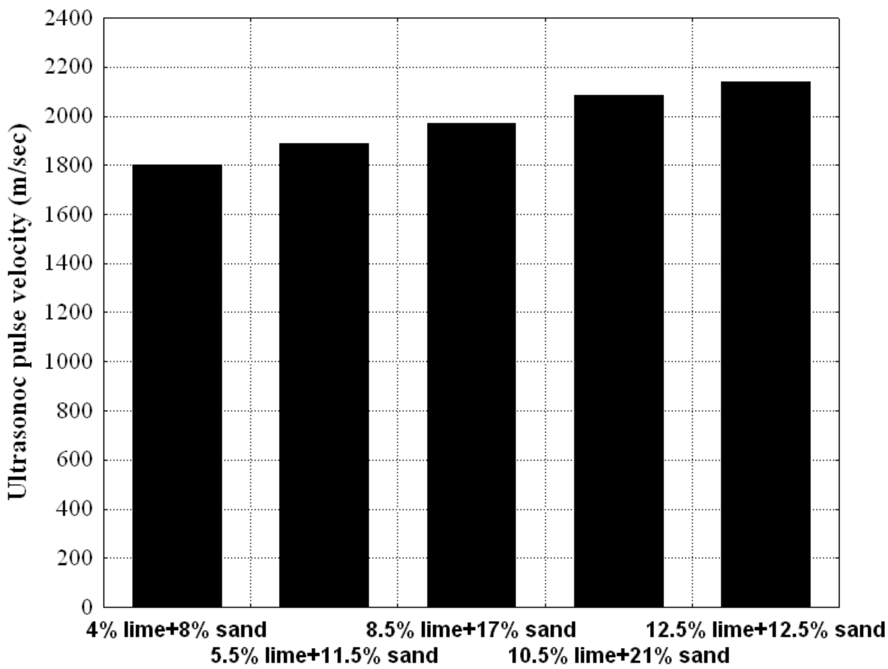

Fig .(15) The ultrasonic pulse velocity of RAP materials plus bricks sand treated with different percentages of hydrated lime and tested after 7 of curing in air.

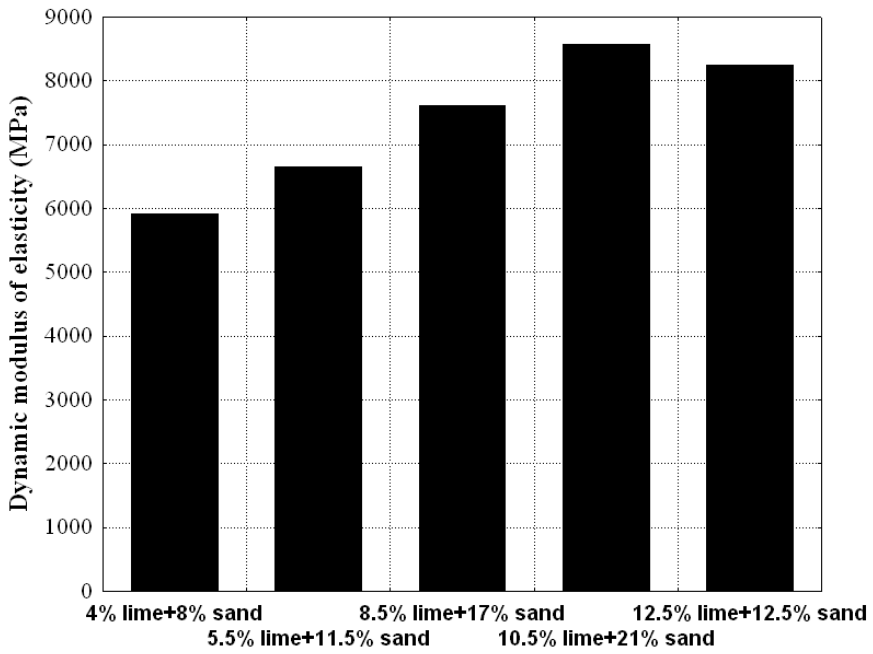

Fig .(16) The dynamic modulus of RAP materials plus bricks sand treated with different percentages of hydrated lime and tested after 7 of curing in air.

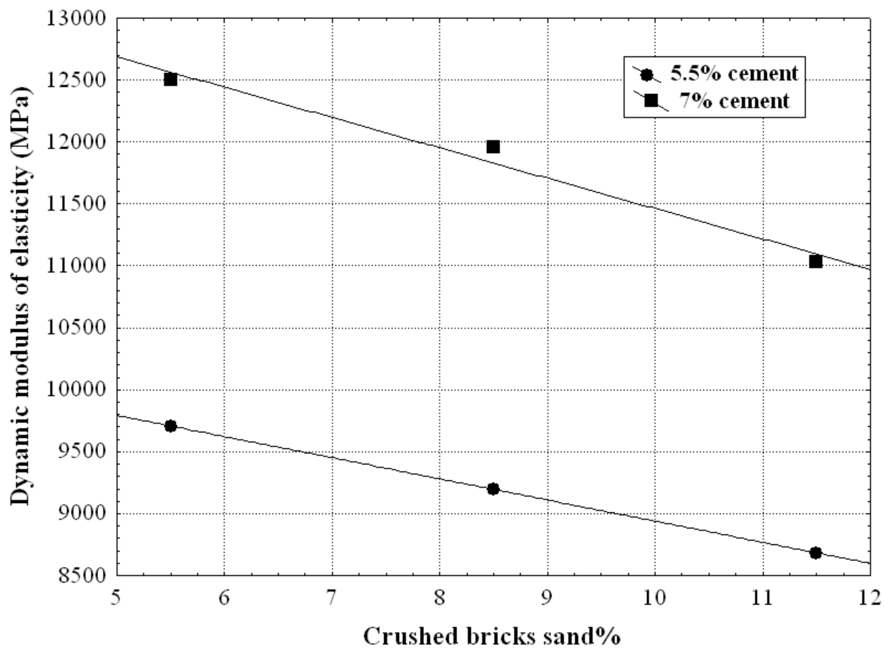

Fig .(17) The dynamic modulus of RAP materials plus bricks sand treated with different percentages of Portland cement and tested after 7 of curing in water.

The ultrasonic pulse velocity of samples stabilized with both lime and cement is affected remarkably with bricks sand content, it decreases with the increase of bricks sand. Also, the ultrasonic pulse velocity is affected by Portland cement content; it increases with the increase of Portland cement content due to increasing of stiffness of samples. **Figure (18)** shows the dynamic modulus of elasticity for samples stabilized with both lime and cement which is a relation to the ultrasonic velocity.

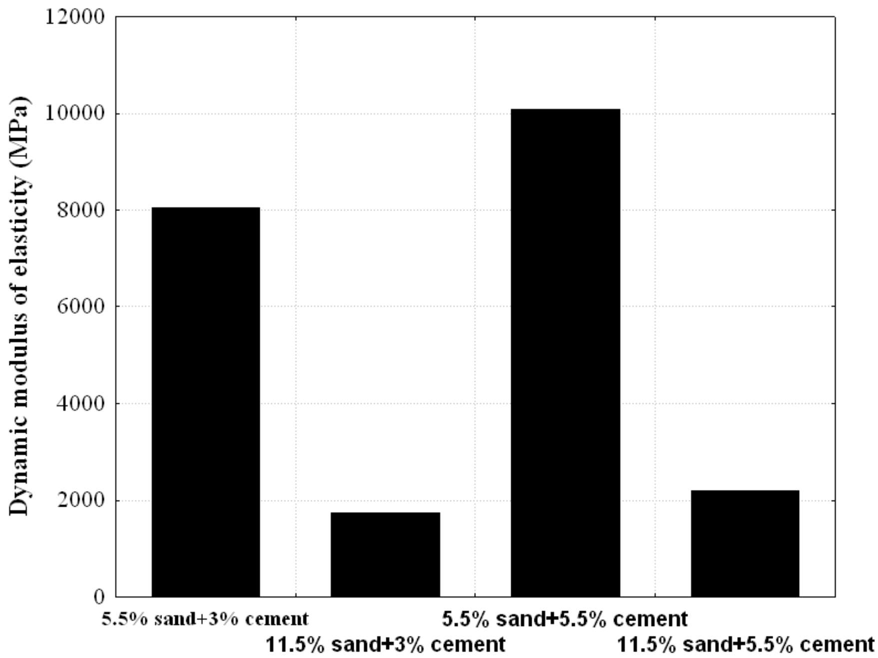

Fig .(18) The dynamic modulus of RAP materials plus bricks sand treated with different percentages of Portland cement and 5.5% hydrated lime and tested after 7 of curing in air.

5. Conclusions

1- Increasing bricks sand in the stabilized RAP materials increase the compression strength because of filling the spaces.
2- Stabilization with Portland cement has higher compression strength than hydrated lime stabilization. The action of bricks sand with lime in immersed samples not good it is increasing the loss in compression strength.
3- Water absorption property influenced with bricks sand increasing, bricks sand increasing reduce the absorption in case of cement stabilizing while with lime increasing the absorption.
4- The dynamic modulus of elasticity value influenced with stabilizer type, in cement stabilization case is higher than with lime but with combine them there is a reduction occurs. It decreases with bricks sand increasing.

5- We recommend the general corporation for highways and bridges to use RAP cold recycling (easy way) with waste bricks and stabilize it with cement for roads construction to benefit from waste materials as aggregate.

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