Journal of Engineering and Development, Vol. 19, No.1, January 2015, ISSN 1813- 7822

An Empirical Relationship Between Asphalt and Water Absorption of Coarse Aggregates in HMA

Lecturer Dr. Talal Hussien Fadhil
Civil Engineering Department, College of Engineering, University of Anbar
talalmudadi@yahoo.com

Lecturer. Hameed Aswad Mohammed
Civil Engineering Department, College of Engineering, University of Anbar
eng_hameed_2010@yahoo.com

Assistant Lecturer Thamier Yousief Ahmed
Civil Engineering Department, College of Engineering, University of Anbar
tha9mir@yahoo.com

Abstract

Asphalt absorbed by aggregates; can be determined either using effective specific gravity or using Bulk Impregnated Specific Gravity(BISG) , the later has been used in this research. Four types of coarse aggregates, taken from four different quarries in Iraq, have been used. The aggregate types classified into crushed and uncrushed and sub classification according to the aggregate sizes had been done. The aim of this research is to find an empirical relationship between asphalt and water absorption by coarse aggregates brought from different source. To achieve this aim, sixty-two coarse aggregate samples were prepared and tested. In this research, three models were developed to predict asphalt absorption depending on water absorption values. Furthermore, High statistical correlation can be expected due to high acceptable estimated values of the coefficients of determination (R^2) such as the values of (R^2) s are 0.89, 0.87, and 0.76 to predict the amount of asphalt absorption by knowing its water absorption for general, crushed, and natural aggregates respectively. Finally, additional two models were developed to predict bulk impregnated specific gravity depending on the aggregate apparent and bulk specific gravities.

Keywords: ***Coarse aggregates, Bulk impregnated specific gravity, HMA, Asphalt absorption, Water absorption***

Journal of Engineering and Development, Vol. 19, No.1, January 2015, ISSN 1813- 7822

علاقة تجريبية بين امتصاص الإسفلت وامتصاص الماء في ا لركام الخشن للخلطات الإسفلتية الحارة

م.د. طلال حسين فاضل م. حميد اسود محمد م.م. ثامر يوسف احمد
قسم الهندسة المدنية / كلية الهندسة / جامعة الانبار

الخلاصة

تمتص حبيبات الركام الأسفلت ، ويمكن إيجاد نسبة امتصاص الاسفلت من قبل الركام إما باستخدام الوزن النوعي الفعال أو استخدام الوزن النوعي ألحجمي للركام المشبع أو المغمور في الإسفلت . تم استخدام الطريقة الأخيرة في هذا البحث.

تم اختبار أربعة أنواع من الركام الخشن والتي أخذت من أربع مقالع مختلفة في العراق. تم تصنيف أنواع الركام إلى ركام مكسر وأخر غير مكسر (الطبيعي) كما تم تصنيفها بتصنيف فرعي أخر وفقا لحجم حبيبات الركام .

إن هدف هذا البحث هو إيجاد علاقة تجريبية رياضية بين نسبة امتصاص الإسفلت وامتصاص الماء لأنواع الركام الخشن المختلف. لغرض تحقيق هذا الهدف، فقد تم تهيئة وفحص اثنان وستون عينة من أنواع الركام الخشن .

في هذا البحث، تم الحصول على ثلاث نماذج رياضية يمكن استخدامها للتنبؤ بنسبة امتصاص الركام الخشن للإسفلت من خلال معرفة نسبة امتصاصها للماء. أعطت هذه النماذج قيما إحصائية عالية من خلال قيم معامل التحديد (R^2).حيث كانت قيم معامل التحديد 0,89 و0,87 و0,76 للنماذج الرياضية الخاصة بتنبوء امتصاص القير من خلال قيم امتصاصها للماء للركام العام (خليط من الركام المكسر والطبيعي) و والركام المكسر والركام الطبيعي بالتتابع.

أخيرا، تم تطوير نموذجين آخرين إضافيين يمكن استخدامهما للتنبؤ لإيجاد الوزن النوعي ألحجمي للركام المغمور في الإسفلت من خلال الاعتماد و معرفة الوزن النوعي الظاهري و الوزن النوعي ألحجمي للركام الخشن المستخدم.

1. Introduction

Asphalt concrete mixture is a composition of aggregates, asphalt binder, and air voids. By volume, a typical hot mix asphalt (HMA) mixture is about 85% aggregates, 10% asphalt binder, and the remaining of about 5% is air voids [1]. High portion of aggregates make the mixture affected greatly by aggregate properties. The aggregate can be classify into coarse, which is defined by Iraqi Standard Specification for Roads and Bridges (ISSRB) as the portion of the combined aggregate retained on the 4.75mm (NO.4 sieve), and fine which is passing through 4.75mm (NO.4 sieve [2].

According to Chadbourn et al., the asphalt absorption process by aggregates may occur continually under high temperatures (between 120 to 170°C) or at any time; during mixing at the HMA plant, storage in a silo, hauling time in trucks, or in service [3]. The binder viscosity, aggregate pore size and its distribution, have a direct effect on the nature and degree of asphalt absorption [4]. Aggregates with high porosities are unsuitable and uneconomic in asphalt concrete mix due to the high amount of the absorbed asphalt.

Coarse aggregates have large and deep porosities, so it absorb more asphalt and need more time to complete absorption process than that in fine aggregate. Alani et al. found that the asphalt absorption increases with the increase in coarse aggregate fractions (3/4 inch to

No.10) for all the sources and gradation [5]. Lee et al. explained that aggregates particle size and shape have an effect on the rate of absorption with smaller aggregates being filled at faster rate [4].

Many problems may occur due to the use of incorrect computation and estimation of asphalt absorption. Some absorption may lead to improve strength in a compacted mixture through particle interlocking [6]. Alani et al. indicated that mixtures containing high absorptive aggregates resulted greater resistance to plastic flow at high temperature[5].

Based on the method, which used to define the volume of the aggregate particles, there are four different aggregate specific gravities used for HMA volumetric analysis [7].

1-Apparent specific gravity, 2- Bulk specific gravity, 3-Effective Specific Gravity (ESG), and 4- Bulk Impregnated Specific Gravity (BISG).The apparent specific gravity includes only the volume of the aggregate particles; it does not include the volume of any pores that filled with water after a 24 hour soaking. Bulk specific gravity includes all the overall volume of aggregate particles as well as the volume of pores that filled with water after a 24 hour soaking. The effective and bulk-impregnated specific gravity includes the overall volume of aggregate particles , plus the pores that become filled with water after a 24 hour soaking , minus the volume of the larger pores that absorb asphalt [7].

The bulk, apparent specific gravity, and water absorption of coarse aggregate are determined according to ASTM C-127 (2004). The ESG of aggregate, from which asphalt absorption is computed, can be obtained by finding maximum specific gravity of loose HMA mixture using Rice specific gravity method [8]. Bulk and apparent specific gravity can relate to individual aggregates or combined aggregates.

ESG relates exclusively to the total combined aggregate structure in a mix of HMA [9]. ESG and asphalt absorption by total weight of aggregate can be calculating from Eqs.(1) and (2) respectively.

$$G_{eff.} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} \qquad \text{.. (1)}$$

$$A_{abs.} = \left(\frac{1}{G_{b.agg.}} - \frac{1}{G_{eff.}} \right) \times G_b \times 100 \qquad \text{.. (2)}$$

Where P_b is percent of asphalt content in total mix, G_{mm} is maximum theoretical specific gravity of mix, G_b is bitumen specific gravity, $A_{abs.}$ is percent of asphalt absorption by total weight of aggregate $G_{b.agg.}$ is bulk specific gravity of aggregate, and $G_{eff.}$ is effective specific gravity of aggregate.

Kandhal and Khatri concluded that, a definite general relationship between the water and asphalt absorption value was observed. Aggregates that absorb more water are likely to absorb more asphalt cement [10]. Alani et al. mentioned, even though the volume of asphalt absorbed is always less than the volume of absorbed water and no consistent relationship between both values can be suggested for prediction of asphalt absorption from water absorption [5].

Kandhal and Khatri showed, by using Rice specific gravity method, that asphalt absorption property may influenced by aging asphalt concrete mixture in the oven at a temperature of 143°C at several times starting from 0 hour (just after mixing) to 8 hours. In addition, they observed an increase in the air voids from 4% at 0 hour to 5.4% after aging for 4 hours [6].

There are two methods that may be use to find absorbed asphalt by aggregates; the first method by applying ESG (result from Rice specific gravity method), and the second one using BISG. Effective and bulk impregnated specific gravities are similar in the concept but vary in some properties. The comparison between these two methods as found by this research, listed in **Table (1).**

Table .(1) Comparison between ESG and BISG

Item	Effective specific gravity ($G_{eff.}$)	Bulk impregnated specific gravity ($G_{imp.}$)
Definition	weight of oven dry aggregate divided by volume of aggregate solid particle plus permeable water voids minus voids filled with asphalt	Same concept of effective specific gravity
Authority	Standard test method ASTM D2041 to find G_{mm} for HMA.	1- U.S. Army Corps of Engineers (1965)[11]. 2-Austroads Guide to Pavement Technology (2005)[12]. 3- Oklahoma (2003)[13].
Object	To find percentage of asphalt which absorbed by aggregates	To find realistic maximum percentage of asphalt which absorbed by aggregates[4]
Dependency	Depending on the value of maximum specific gravity of HMA mixture (G_{mm}).	Independent
Applicability	Only for loose asphalt concrete mixture	1-For coarse, fine aggregate individually, and combination of them. 2-For loose asphalt concrete mixture
Accuracy	Less accurate due to dependency	More accurate due to independency

2. Aim of the Study

The aim of this research is to find a relationship between asphalt and water absorption, of coarse aggregates taken from different sources in north and west of Baghdad and then developing models that can be used to predict the amount of asphalt absorption according to their water absorption. In addition, to find out which type of aggregates have a high ability to absorb asphalt.

3. Experiments and Materials

3.1. Experiments

ASTM C-127 (2004), standard test method was followed to find water absorption, bulk, and apparent specific gravity for each sample of coarse aggregate.

The BISG test method procedure, adopted by U.S. Army Corps of Engineers (1965)[11], and authorized by Austroads guide to pavement technology[12] and Oklahoma D.O.[13], was used to compute the realistic maximum asphalt absorption by individual coarse aggregate fractions.

The following points describe the main procedure of the test method as stated in Mil-STD-620a-method 105 [11]:

1- Dry the aggregate sample to a constant weight at temperature 110°C for minimum 8 hours, cool at room temperature and weigh to the nearest 0.1gm. (Dry aggregate weight as = ***A***)

2- Heat asphalt to 138°C ± 5, and pour sufficient amount in to 1- gal pail about one third full. Insert a metal stirrer and allow pail and content to cool to 25°C.

3- Weigh pail plus asphalt and stirrer in air at room temperature (as = ***B***) and in water at 25°C (as = ***C***).

4- Place the pail of asphalt with stirrer and also the sample of aggregate in an oven maintained at a temperature of 138°C ± 5 and leave both until temperatures are equalized (a minimum of 4 hours is usually required).

5- Remove aggregate, asphalt from oven, and add aggregate gradually to the hot asphalt while stirring thoroughly. Continue to stir uniformly after all aggregate is added until the total elapsed time from start of mixing to end of stirring is 2 minutes. Cool to 25°C. If such air present, flame surface during the cooling period to remove air bubbles.

6- Weigh pail plus stirrer plus aggregate and asphalt in air at room temperature (as = ***D***) and in water at 25°C (as = ***E)***.

The BISP ***(G_{imp})*** and asphalt absorption ***($A_{abs.}$)*** can be computed from Eqs.(3) and (4) respectively.

$$G_{imp} = \frac{A}{(D-E)-(B-C)} \qquad \text{.. (3)}$$

$$A_{abs.} = \left(\frac{1}{G_{b.agg.}} - \frac{1}{G_{imp}} \right) \times G_b \times 100 \qquad \text{.. (4)}$$

3.2. Materials

In this research, four types of coarse aggregate taken from four different quarries in Iraq were tested. The first two types taken from the north of Baghdad - Samarra, and Nebaee quarries, while the remaining two types taken from the west of Baghdad- Anbar province; Jharyishie and Asiylla quarries. All the aggregate types classified into crushed and uncrushed (natural) and sub classification was done according to the size of aggregates.

At the beginning, four samples per each size of crushed aggregate type from Jharyishie quarry were tested. Later on, duplicate samples taken for each quarry (for each type and size). The total prepared and tested samples were sixty-two.

In order to encoding each type of aggregate test sample, several symbols had been use; for example symbol (CN3/4), which can be described as; C for crushed aggregate type , N for quarry type (here Nebaee), and 3/4 for aggregate size passing sieve 1 inch retained on sieve 3/4 inch. For another symbol (NN3/4), same as previous explanation except that the first letter (N) indicating to natural aggregate (uncrushed). Average physical properties of the used aggregate containing all types of fraction size (four fractions from remaining on sieve 3/4 inch to remaining on sieve No.4) from each quarry are listed in **Table (2).** Only one type of Iraqi asphalt cement having grade of (40-50), taken from Bajee Refinery, was used in this research. General properties of used asphalt cement shown in **Table (3).**

Table .(2) Physical Properties of Used Aggregates [Anbar Un. lab]

Material	Average value of all fractions				
	Bulk sp. Gr.	Apparent Sp. Gr.	% Water absorption	% of wear (Los Angeles)	Degree of crushing
Crushed Nebaee (CN)	2.646	2.677	0.480	19.18	94.7%
Natural Nebaee (NN)	2.653	2.690	0.481	15.49	0%
Crushed Asiylla (CA)	2.582	2.637	0.912	27.89	96.0%
Natural Asiylla (NA)	2.612	2.659	0.685	24.5	0%
Crushed Jharyishie(CJ)	2.605	2.633	0.478	22.6	93.5%
Natural Jharyishie(NJ)	2.608	2.643	0.422	20	0%
Natural Samara(NS)	2.661	2.701	0.507	15.5	0%

Table .(3) General Properties of Used Asphalt Cement. [Anbar Un. lab]

Property	Designation	Unit	Results
Penetration (25°C, 100g, 5 sec.)	ASTM- D5	0.1mm	44
Ductility (25°C, 5cm/min.)	ASTM - D 113	cm	+100
Softening Point (Ring and Ball)	ASTM- D 36	°C	47
Viscosity at 135°C (Rotational Viscometer)	ASTM – D 4402	mPa.s	487
Specific Gravity at 24°C.	ASTM - D 70		1.04
Solubility in Trichloroethylene (% Min.)	ASTM - D 2042	%	99.5

4. Results and Analysis

4.1. Water and asphalt absorption

According to the data shown in **Figures (1) and (2),** aggregates from all quarry types had more ability to absorb water than asphalt. The percent of asphalt and water absorption varies from one quarry to another. In general ,it was noticed that crushed aggregates had absorbed asphalt more than that of natural aggregate due to its rough surface texture and of having higher surface area; hence it had higher ability to absorb both water and asphalt than natural rounded aggregates. It was observed that both natural and crushed aggregates, from Nebaee and Jharyishie quarry, have the same trend of absorption to water and asphalt at temperature of more than 120°C.

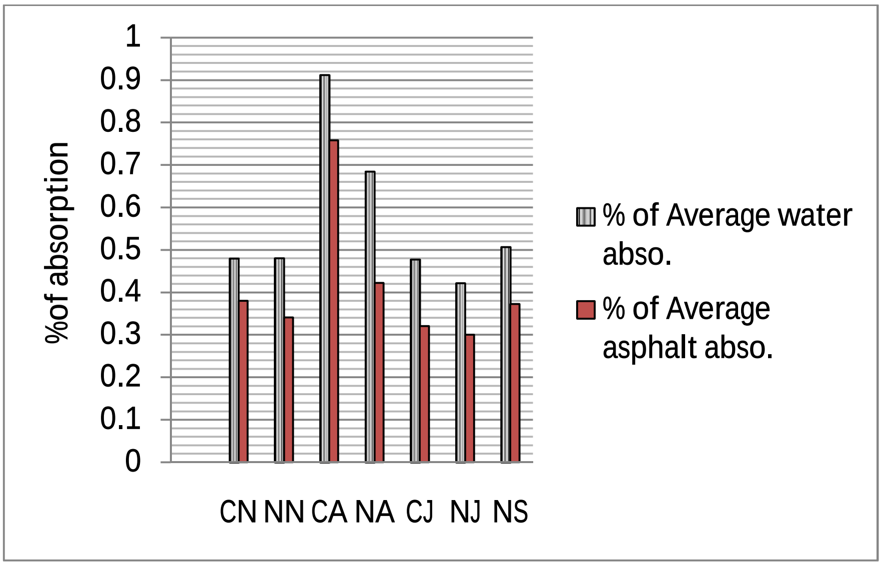

Fig .(1) Percents of Absorbed Water & Asphalt by Aggregates from Different Quarries

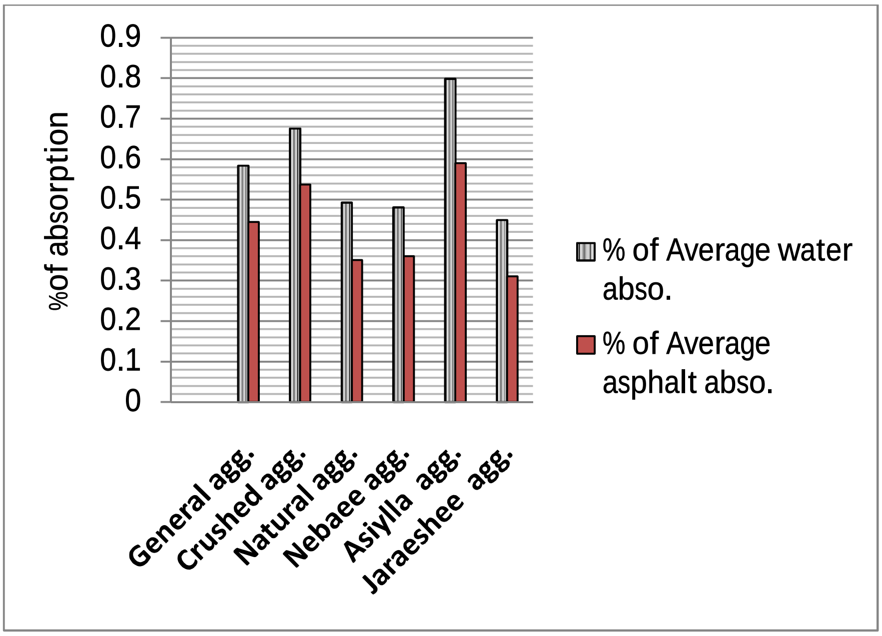

Fig .(2) Percent of Absorbed Water & Asphalt by Each Individual Type of Aggregate

As shown in **Figure (1),** crushed aggregate from Asiylla quarry showed higher degree of absorption (as a percent from total weight of aggregates which is equal to 0.912% for water and 0.758% for asphalt) than natural aggregate for the same quarry (0.685% for water and 0.422% for asphalt). However, generally this aggregate had trend to absorb water and asphalt more than other quarry aggregates. The main reason behind this behavior was due to high porosity and pore size distribution on the surface of Asiylla aggregates as shown in **Plate (1).** Shapes of other aggregate types are similar to that exhibited in **Plate (2).**

Plate .(1) Asiylla Quarry Aggregate

Plate .(2) Nebaee Quarry Aggregate

4.1.1. Model Development

The average of duplicate test values was adopted and it's result values were used to obtain a relationship between water and asphalt absorption. These relationships together with the best–fit lines for crushed, natural, and general aggregates (combined of natural and crushed aggregates) are shown in **Figures (3), (4), and (5**) respectively.

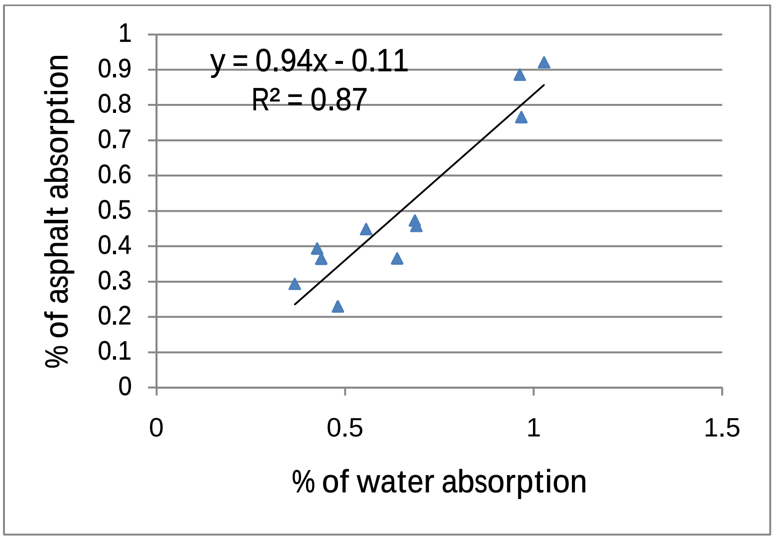

Fig .(3) Relationship between Water and Asphalt Absorption by Crushed Aggregate

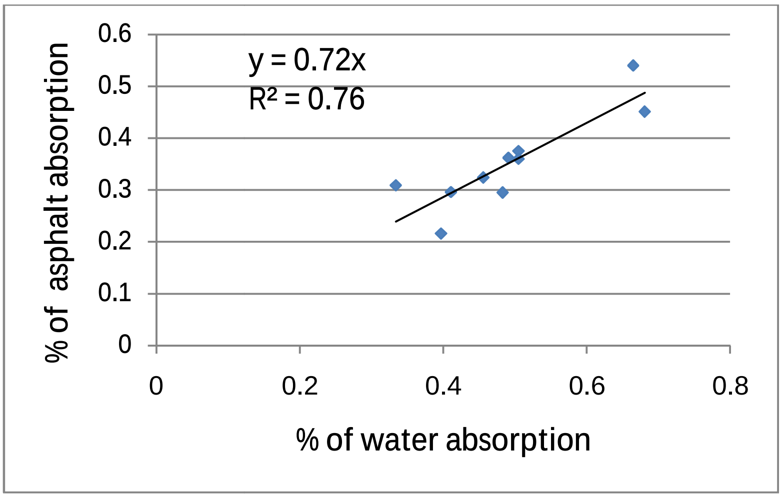

Fig .(4) Relationship between Water and Asphalt Absorption for Natural Aggregates

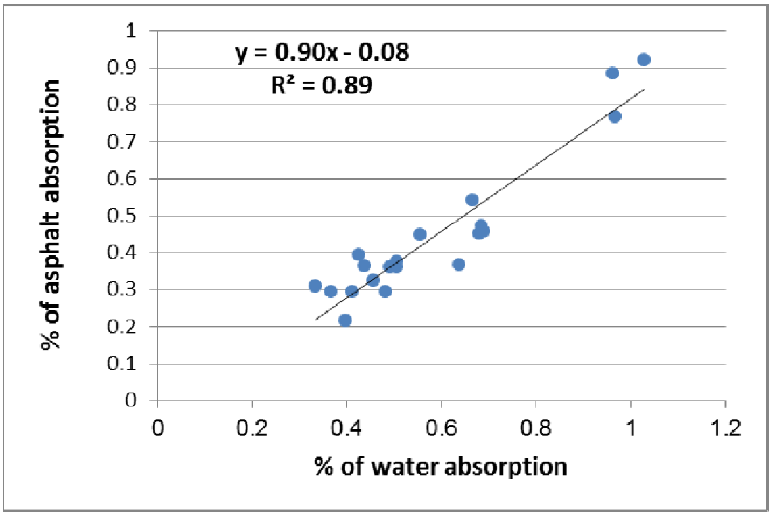

Fig .(5) Relationship between Water and Asphalt Absorption for General Aggregates

From linear regression, the following models were obtained:

1- For General aggregate

$\%A_{abs.} = 0.90 \times \%W_{abs.} - 0.08$, (*gave* $R^2 = 0.89$) .... (5)

2- For Crushed aggregate

$\%A_{abs.} = 0.94 \times \%W_{abs.} - 0.11$, (*gave* $R^2 = 0.87$), ... (6)

3- For Natural aggregate

$\%A_{abs.} = 0.72 \times \%W_{abs.}$, (*gave* $R^2 = 0.76$), ... (7)

The coefficient of determination (R^2) of these models related to general aggregates model was higher than that for crushed and normal aggregate models. This is due to being the sample size of the general aggregates was larger than that used for crushed and natural aggregates.

4.2. Effective, apparent, and bulk specific gravities

The value of the ESG for each type of aggregate cannot be found unless maximum specific gravity of HMA firstly determined by using Rice specific gravity method. Due to this criterion, the superpave mix design method suggested an equation to estimate the ESG based on the known values of apparent and bulk specific gravities as shown in Eq.(8) [14]:

$$G_{eff.} = G_{bulk} + F \times (G_{app.} - G_{bulk}) \quad \text{...} (8)$$

Where F is a factor equal to 0.8 for normal aggregate and for absorptive aggregates may require F values closer to 0.6 or 0.5 [14].

In this research, BISG ($G_{imp.}$) has adopted instead of ESG of aggregates for two reasons: First, the air void value, computed in laboratory during the preparation process of job mix formula, was restricted as 4% according to ISSRB specification. Due to aggregate absorption process, air void was changing from time to another that leading to reduction in effective asphalt content. The main changes were starting from mixing in the plant and continuing until the road opened to traffic motion. Accordingly, it is better to use maximum realistic asphalt absorption criterion, which can be handle, by using BISG. When BISG applied, the value of air void can be keep approximately constant. Second, because the definition of BISG is similar to that of ESG.

To calculate the average value of the constant(F) of current study, research data which representing bulk and apparent specific gravities are applied and used in superpave equation (see Eq. 8). The gained of average value of F factor was 0.735, substituted in Eq. (8) leading to a new model for the current work expressed as:

$$G_{imp.} = G_{bulk} + 0.735\,(G_{app.} - G_{bulk}) \quad \text{...} (9)$$

By utilizing SPSS software program, another model was accomplished from the research data representing of apparent, bulk, and impregnated specific gravities of used aggregates; equation (10) shows this model.

$$G_{imp.} = 0.31 + 0.407\,G_{app.} + 0.48\,G_{bulk} \quad \text{...} (10)$$

The above three models (i.e. Eq. 8, Eq. 9, and Eq. 10) were executed to find different values of ($G_{imp.}$). All values of ($G_{imp.}$), Which obtained from three models and forth value representing observed of ($G_{imp.}$) which found by laboratory work are used as an input data in SPSS software program. SPSS software program output, shown in Table 4.

Table (4) ,shows the matrix of comparison and the correlations between observed and calculated G_{imp} values. From this Table, the positive high significant correlations between the observed and calculated values were clear due to value of p, which is found to be 0.01.

The limitation values of apparent, bulk, and impregnated specific gravities, which can be used in models representing Eq. 8, Eq. 9, and Eq. 10, and more descriptive statistics are shown in **Table (5) .**

Table .(4) Correlations between Observed and calculated Specific Gravities

		G_{imp} observed	For F=0.735	For F=0.8	From SPSS
G_{imp} observed	Pearson Correlation	1	.927**	.923**	.934**
	Sig. (2-tailed)		.000	.000	.000
	N	27	27	27	27
For F=0.735	Pearson Correlation	.927**	1	1.000**	.992**
	Sig. (2-tailed)	.000		.000	.000
	N	27	27	27	27
For F=0.8	Pearson Correlation	.923**	1.000**	1	.988**
	Sig. (2-tailed)	.000	.000		.000
	N	27	27	27	27
From SPSS	Pearson Correlation	.934**	.992**	.988**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	27	27	27	27

**. Correlation is significant at the 0.01 level (2-tailed).

Table .(5) limitations and descriptive statistics of specific gravities

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
G_{imp}	27	.093	2.608	2.701	2.65007	.005016	.026066	.001
G_{app}	27	.086	2.622	2.708	2.66133	.005155	.026788	.001
G_{bulk}	27	.103	2.573	2.676	2.62241	.005660	.029409	.001
Valid N(listwise)	27							

Figures (6), (7), and (8) show the scatter diagram which explain a relationship between observed and predicted ($G_{imp.}$) values. From these relationships, the predicted correlation obtained by SPSS software program gave higher correlation of (r = 0.935) as compare with what was obtained by from Eq.(9) with (r=0.927) and the last one from Eq.(10) with (r) value of 0.923. In general all the models gave accurate relationships with good correlation since the (r) values are greater than 0.9.

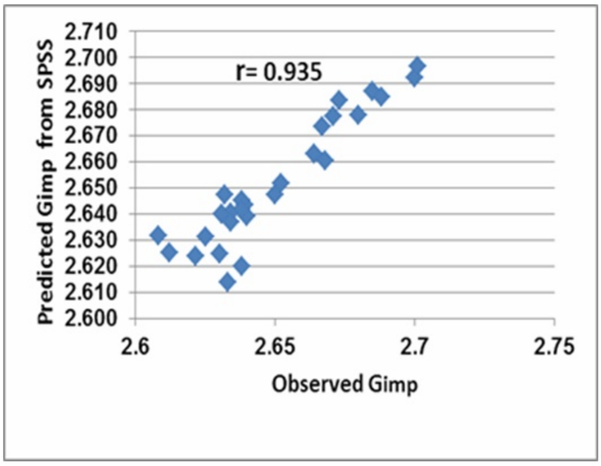

Fig .(6) Predicted *(G_{imp})* from SPSS vs. observed *($G_{imp.}$)* values

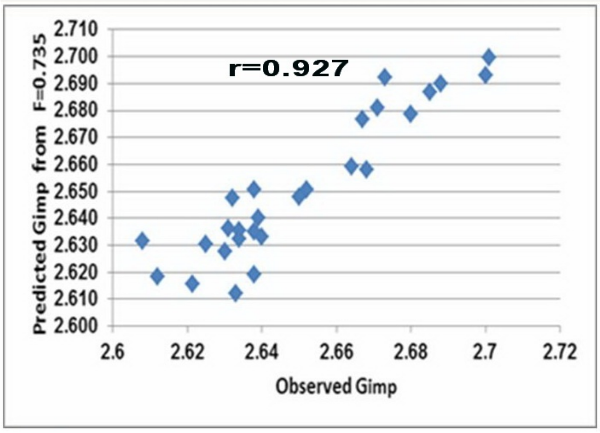

Fig .(7) Predicted *(G_{imp})* from equation of *F*=0.735 vs. observed *($G_{imp.}$)* values.

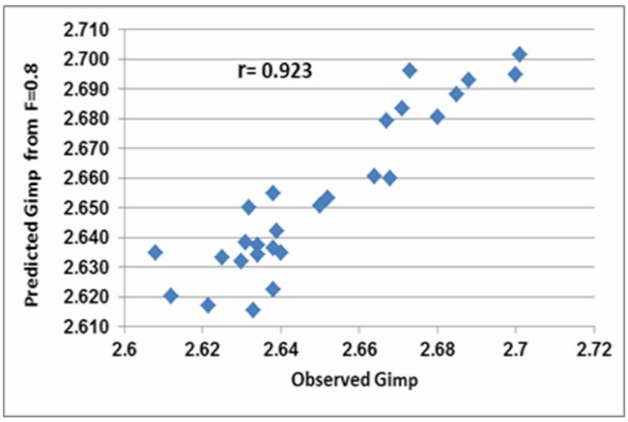

Fig .(8) Predicted *(G_{imp})* from equation of *F*=0.8 vs. observed *($G_{imp.}$)* values.

5. Conclusion

1- In general; higher absorption values of water and asphalt can be observed for crushed aggregates which have rough texture with large surface area, and the aggregates obtained from Asiylla quarry due to its nature shape, if compared with the other types.

2- Three models have been developed to predict asphalt absorption. In order to run these models the value of water absorption must be known. These models have high correlation values as shown in **Table (6).**

Table .(6) Developed Models

Aggregate type	Model	R^2	Limitation for $\%W_{abs}$ values	
			Max. $\%W_{abs}$	Min. $\%W_{abs}$
General aggregate	$\%A_{abs.} = 0.90 \times \%W_{abs.} - 0.08$	0.89	1.027	0.334
Crushed aggregate	$\%A_{abs.} = 0.94 \times \%W_{abs.} - 0.11$	0.87	1.027	0.367
Natural aggregate	$\%A_{abs.} = 0.72 \times \%W_{abs}$	0.76	0.681	0.334

3- BISG of aggregates give maximum realistic percentage of asphalt absorption that mean minimum availability of air voids in the asphalt concrete mix. ESG value depends on the amount of air void percentage in total HMA, that mean, if still there is presence of porosities in aggregate not filled by asphalt, this will lead and permit additional asphalt substance to move inside aggregate porosities specially under high temperatures (120°C to170°C) through different operations of asphalt concrete manufacturing and construction. Operations start in asphalt plant during mixing, storing, hauling time in trucks, paving, and finally compacting in situ, and this will lead to reduction in asphalt content and finally increasing in the value of air voids.

4- Two models were developed to predict Gimp. To use these models, the values of aggregate apparent and bulk specific gravities need to be known. Good agreement was observed between observed and predicted Gimp and strong correlations were achieved by both models.

6. Recommendations

Future studies need to show the effect of the application of BISG instead of ESG on the estimation of the amount of asphalt absorbed by HMA laboratory samples, and comparing it with that found from the field at two stages; first stage immediately after the complete compaction of the pavement surface and before opening road to traffic. Second stage at different time periods to study the effects of time on increasing air voids due to tendency of asphalt, under different factors, to penetrate into aggregate voids result in reducing effective asphalt content then leading to additional air voids added to original air voids.

7. References

1. **NCHR Report 673. (2011)." A Manual for Design of Hot Mix Asphalt With Commentary.", Transportation Research Board (TRB) Washington D.C. USA, P.P4.**
2. **The State Corporation for Roads and Bridges.(2003)." Iraqi Standard Specifications for Roads and Bridges (ISSRB) ." R9,Revised Edition, Iraq, P.P 2.**
3. **Chadbourn, B., A., Skok, E., L., Crow, B., L., Spindler, S., and Newcomb, D., E. (2000). "The Effect of Voids in Mineral Aggregate (VMA) on Hot-Mix Asphalt Pavements." Minnesota Department of Transportation, USA, March P.P16-17.**
4. **Lee, Y., D., Guinn, A.,J., Khandal, S.,P., and Dunning, L.,R.,(1990)."Absorption of Asphalt Into Porous Aggregates." Strategic Highway Research Program, National Research Council, Washington, USA, P.P7.**
5. **Alani, H.,M., Mansour, S.,L., and Hasso, H., G. (1987). " Asphalt Absorption by Aggregates, Effect on Paving Mixtures."Al-muhandis: Journal of Iraqi Society of Engineers, Baghdad, Iraq, P.P 3-8.**
6. **Khandal, S.,P., and Khatri, M., A. (1991). "Evaluation of Asphalt Absorption by Mineral Aggregates." NCAT Report 91-04, Auburn University, USA, P.P. 11-13.**
7. **Roberts, F., L., Khandal, S.,P., Brown E., R., Lee, Y., D., and Kennedy, T., W.(1996). " Hot Mix Asphalt Materials, Mixture Design and Construction." Second Edition, National Center for Asphalt Technology (NCAT), Auburn University, USA, P.P. 145-147.**
8. **American Society for Testing and Material (ASTM).(2004)." Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate."C127-01, Annual Book of ASTM Standards, Vol.4, USA**
9. **Asphalt Institute.(2007)." The Asphalt Handbook." Seventh Edition, USA, 2007,P.P129.**
10. **Khandal, S.,P., and Khatri, M., A.(1992). " Relating Asphalt Absorption to properties of Asphalt Cement and Aggregates." NCAT Report No.92-02,Annual Meeting of the Transportation Research Board, Washington ,USA, P.P17.**
11. **U.S. Army Corps of Engineers.(1965). " Determination of Bulk-Impregnated Specific Gravity of Aggregate Proposed for Use in Bituminous Paving Mixes. " Mil-STD-620 a method 105, USA.**
12. **Austroads Guide to Pavement Technology.(2005). "Absorption of Bituminous Binder into Aggregate. " AG:PT/T052, Australian.**
13. **Oklahoma, D.,O.(2003). " Method of Test for Bulk Impregnated Specific Gravity of Aggregate ", OHD L-7.**
14. **National Highway Institute (NHI) (2001). "Superpave Fundamentals: Reference Manual." Course #131053, Federal Highway Administration (FHWA).U.S. Department of Transportation, USA, P.P VII-8.**