INFLUENCE OF DEGREE OF CRUSHING OF COARSE AGGREGATE ON PROPERTIES OF ASPHALT PAVING MIXTURES USED FOR SURFACE COURSES

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Abstract

There are several properties of coarse aggregate used in hot mix hot laid asphalt concrete mixtures such as surface texture, percentage of crushing, polished stone value, coating and stripping and percentage of wear that are influence the behavior of asphalt paving mixtures. The effect of percentage of crushing of coarse aggregate used in asphalt concrete mixtures prepared to surface courses according to the standard specification for roads and bridges in Iraq has been studied. Four percentages of crushing of coarse aggregate (0%, 40%, 70% and 100%) selected to indicate the influence of percentage of crushing on asphalt concrete mixture properties (bulk specific gravity, % air voids, % voids in mineral aggregate, Marshall stability, Marshall flow, indirect tensile strength, index of retained strength). According to this study, the mixtures with 40% fractured coarse aggregate accommodate the requirements of Iraqi specification of roads and bridges (SCRB).

Key Words: Asphalt concrete, % of Crushing, Coarse aggregate, Marshal stability, standard specification.

تأثير نسبة التكسير للحصى الخشن على خواص الخلطات الإسفلتية المستخدمة للطبقات السطحية

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الملخص

توجد خواص كثيرة للحصى الخشن المستعمل في الخلطات الإسفلتية الممزوجة بدرجات الحرارة العالية والمفروشة بدرجات حرارة عالية مثل نوعية سطح الحبيبات، نسبة التكسير، قيمة صقل الحجر، التقشر، ونسبة التآكل وكل هذه الخواص تؤثر على سلوك الأداء لخلطات التبليط الإسفلتية. في هذه الدراسة تم دراسة تأثير نسبة التكسير للحصى المستخدم للخلطات الإسفلتية المحضرة للطبقات السطحية حسب المواصفات القياسية للطرق والجسور العراقية. تم اختيار أربع نسب مختلفة لدرجة تكسير الحصى (٠%، ٤٠%، ٧٠% و ١٠٠%) لتحديد تأثير نسبة التكسير على الخواص الفيزيائية للخلطات الإسفلتية (الوزن النوعي للخلطة، نسبة الفجوات الهوائية، نسبة الفراغات بالركام، ثبات مارشال، جريان مارشال، ومقاومة الشد الغير مباشر ونسبة المقاومة المسترجعة). وبحسب هذه الدراسة وجد بان الخلطات الإسفلتية التي تحتوي على ركام خشن بنسبة تكسير تساوي٤٠% تستوفي متطلبات المواصفات القياسية العراقية للطرق والجسور (SCRB) للطبقة السطحية.

Nomenclature:

AASHTO: American Association of State Highway and Transportation Officials
ASTM: American State of Testing and Materials
IRS: Index of Retained Strength
ITS: Indirect Tensile Strength
SCRB: State Corporation for Roads and Bridges
SHRP: Strategic Highway Research Program
SORB: State Organization of Roads and Bridges in Iraq
SUPERPAVE: Superior Performing Asphalt Pavements
VMA: Voids in Mineral Aggregate

Introduction

Asphaltic mixtures are a uniformly mixed combination of asphalt cement, coarse aggregate, fine aggregate and other materials, depending on the type of asphalt mixture. The different, types of asphaltic concretes commonly used in pavement conduction are hot-mix, hot-laid and cold-mix, cold-laid. Asphaltic concrete is the most popular paving material used in Iraq. When used in the construction of highway pavements, it must resist deformation from imposed traffic loads, be skid resistant even when wear and not be easily affected by weathering forces. The degree to which an asphaltic concrete achieves these characteristics is mainly dependent on the design of the mix used in producing the concrete (Garber 2009).

Hot-Mix Hot-Laid Asphaltic Concrete:

Hot-mix, hot-laid asphaltic concrete is produced by properly blending asphalt cement, coarse aggregate, fine aggregate, and filler (dust) at temperatures ranging from about 175 °F to 325 °F, depending on the type of asphalt cement used. Suitable types of asphaltic materials include AC-20, AC-10, and AR-8000 with penetration grades of 60-70, 85-100, 120-150, and 200-300. Hot-mix, hot-laid asphaltic concrete is normally used for high-type pavement construction, and the mixture can be described as open-graded, coarse-graded, dense-graded, or fine-graded. When produced for high-type surfacing, maximum sizes of aggregates normally range from 3/8 in. to 3/4 in. for open-graded mixtures, 1/2 in. to 3/4 in. for coarse-graded mixtures, 1/2 in. to 1 in. for dense-graded mixtures, and 1/2 in. to 3/4 in. for fine-graded mixtures. When used as base, maximum sizes of aggregates are usually 3/4 in. to 1 1/2 in. for open- and coarse-graded 1 in. to 1 1/2 in for dense grades and 3/4 in. for fine-graded mixtures. As stated earlier, the extent to which an asphalt concrete meets the desired characteristics for highway pavement construction is dependent mainly on the mix design which involves the selection and preparing of the different material components. However, note that when designing hot mix asphalts concrete, a favorable balance must be found between a highly stable product and a durable one therefore the overall objective of the mix design is to determine an optimum blend of the different components that will satisfy the requirements of the given specifications (Garber 2009).

Aggregate Gradation

Aggregate are usually categorized as crushed rock, sand, and filler. The rock material is predominantly coarse aggregate retained in a No.8 sieve, sand is predominantly fine aggregate passing the No.8 sieve, and filled is predominantly mineral dust that passes the No. 200 sieve. It is customary for gradations of the combined aggregate and the individual fractions to be specified. The first phase in any mix deign is the selection and combination of aggregates to obtain a gradation within the limits prescribed. This is sometimes referred to mechanical stabilization.

Consensus Aggregate Properties

The pavement experts agreed that certain aggregate characteristics are critical to well performing asphalt mixtures. These characteristics are called "consensus properties" because there was wide agreement in their use and specified values. Those properties are coarse and fine aggregate angularity, flat and elongated particles, and bulk and apparent specific gravity (SP-2, 2000).

The aggregate was washed to ensure that all materials are clean, free from injurious amounts of clay balls and clay coated particles, organic matter and other deleterious substances.

Coarse and Fine Aggregate Angularity

Coarse and fine aggregate angularity property ensure a high degree of aggregate internal friction and rutting resistance. The coarse aggregate angularity is determined by degree of crushing which is defined as the percent by weight of aggregate larger than 4.75 mm with one or more fractured face according to SCRB requirements (SCRB (2003)).

The degree of crushing (testing according to ASTM D5821) shall be such that at least 90% by weight of the materials retained on the No. 4 (4.75 mm) sieve has one or more fractured faces (SCRB (2003),and in the other hand AASHTO requirements for the conventional mixtures (dense or open graded) shall be at least 40% (AASHTO 2004).

The fine aggregate angularity is defined as the percent air voids present in loosely compacted aggregates smaller than 2.36 mm "Test Method for Uncompacted Void Content of Fine Aggregate (as influenced by Particle Shape, Surface Texture, and Grading)" under designation (AASHTO TP33) (Asphalt Institute (2000)). Asphalt Institute manual (Asphalt Institute (2000) is devoted to SUPERPAVE mixture design and analysis. SUPERPAVE is short for Superior Performing Asphalt Pavements. Higher void contents mean more fractured faces (SP-2, 2000).

Asphalt Content

Having determined a suitable mix of aggregates, the next step is to determine the optimum percentage of asphalt that should be used in the asphalt concrete mixture. This percentage should, of course, be within the prescribed limits. The gradation of the aggregate determined earlier and the optimum amount of asphalt cement determined combine to give the proportions of the different materials to be used in producing the hot mix hot–laid concrete for the project under consideration. These determined proportions are usually referred to as the job- mix formula.

Two commonly used methods to determine the optimum asphalt content are the Marshall method and the Hveem method (Garber 2009).

Scope of the Study

The main purpose of this study is to evaluate the effect of percentage of crushing of coarse aggregate used in asphalt concrete mixtures that is recommended for surface courses. Four percentage of crushing are used in this study that are (0%, 40%, 70% and 100%) to indicate these effect on the properties of asphalt concrete mixtures and to compare the results with the SCRB specifications and AASHTO requirements .

Materials And Testing Program

Materials

The materials (asphalt cement, aggregate and filler) used in this study are widely available and currently used in road paving in Iraq.

Asphalt cement

One type of asphalt cement (40-50 penetration grade) produced from alshuaba refinery is used in this work, physical properties and other necessary tests for this asphalt cement are presented in **Table (1)**.

Aggregates (coarse and fine materials):

A coarse aggregate used in this work is brought from the hot mix plant at Alnajaf city, the source of aggregate is from Nibaee quarry. The combined gradation of aggregates and filler is shown in **Table (2)** according to specification for roads and bridges (SCRB R/9 (2003)) for surface course with maximum size of 12.5 mm.

The Chemical composition and physical properties of the aggregate are indicated in **Tables (3)** and **(4)** respectively.

Mineral filler:

One type of filler is used in this work which limestone dust collected from materials was passing sieve No. 200. The physical properties of the limestone dust are shown in **Table (5).**

Test Methods

Three methods for testing which are used in this study to evaluate the influence of degree of crushing of coarse aggregate on properties of asphalt concrete mixture, these are:

Marshall Test Method, (D1559).
Indirect Tensile Strength (I. T.S.), (D4123)
Index of Retained Strength (I. R. S.), (D1075).

Mixture preparation:

The aggregates are dried to constant weight at 110 °C, and then separated into the desired sizes to meet the required gradation for the mixtures, as shown in table (2). After heated aggregate and asphalt cement to the temperature which produced a Kinematic viscosity of (170± 20) centistokes (up to 163 °C as an upper limit), then we add the amount of asphalt cement to the heated aggregate, and mixed thoroughly until all aggregate particles are coated with asphalt. A constant mixing temperature is followed in this work with about 150 °C.

Resistance to Plastic Flow of Asphalt Concrete Mixtures (Marshall Method (D1559)):

Procedure of preparation and testing specimens according to this method is described in ASTM D 1559. This method covers the measure of the resistance to plastic flow of cylindrical specimens (2.5 in. height × 4.0 in. diameter) of asphalt paving mix loaded on the lateral surface of specimen by means of Marshall apparatus with a constant rate of 50.8 mm/min (2 in./min) until the maximum load is reached. The maximum load resistance and the corresponding strain values are recorded as Marshall stability and flow respectively, at test temperature of 60 °C.

Three specimens for each combination were prepared and average results are reported.

The bulk specific gravity and density (ASTM D2726), and percent air voids (ASTM D3203) are determined for each specimen. The test specimens are compacted using 75 blows/end according to the SCRB.

Indirect Tensile Strength (D4123):

The method of mixing and the dimensions of the specimens, as well as, the number of blows by compaction hammer remained as those described for Marshall Test.

ASTM D4123 method which determined the indirect tensile strength of asphalt concrete mixture has been used for this purpose.

The specimens brought to the specified test temperature (25 °C) by immersing them in water bath at the temperature for 30-40 minutes, then tested for indirect tensile strength at a rate of 50.8 mm/min using a 1/2 in. wide, curved, stainless steel loading strip on both the top and bottom, running parallel to the axis of the cylindrical specimens, until reaching the ultimate load resistance. Indirect tensile strength (ITS) is calculated from the following equation ASTM D 4123 (ASTM, 1995):

$$ITS = {}^{2P_{ult}}/_{(\pi t D)} \qquad \text{...... (1)}$$

Where:
ITS=Indirect Tensile Strength (Kg/cm^2),
P_{ult}= ultimate applied load (Kg),
T= thickness of the specimen (cm), and
D=diameter of the specimen (cm).

Index of Retained Strength (D1075):

Index of retained strength test is used to evaluate moisture damage of asphalt pavement. This test is also called "Effect of Water on Cohesion of Compacted Bituminous Mixtures" as in ASTM D1075 (ASTM 1995). It is one of tests required by SCRB specifications to be performed on asphalt mixes used in surface course in addition to Marshall Test. This test is intended to measure the loss of cohesion resulting from the action of water on compacted bituminous mixtures penetration grade asphalt.

The method of mixing and the dimensions of the specimens, as well as, the number of blows by compaction hammer remained as those described for Marshall Test.
ASTM D1075 (ASTM 1995) described the method for determine the index of retained strength; in this study we take Marshall test procedure to determine I.R.S %.
The numerical index of resistance of bituminous mixtures to the detrimental effect of water was expressed as the percentage of the original strength that was retained after the immersion period. It is calculated as follows:

$$I.R.S. = \frac{S_2}{S_1} \times 100\% \qquad \text{..... (2)}$$

Where:
I.R.S.= Index of Retained strength (%)
S_1= Marshall Stability of specimens immersed in water bath for (30-40 minutes) at 60 ◦C before testing, KN
S_2= Marshall Stability of specimens immersion for 24 hours at 60 ◦C before testing, KN

Test Program of This Study:

In this study we have been considered the effect of degree of crushing for coarse aggregate on asphalt concrete mixture properties recommended to use as surface course according to SCRB R/9. **Table (6)** gives the detailed information about the different mixture combination and tests performed in the experimental plan adopted in this work.

Results and Discussion

To evaluate the influence of degree of crushing of coarse aggregate used in surface course, different tests were conducted on mixture properties. That is including bulk density, air voids, voids in mineral aggregate, Marshall Stability, Marshall Flow, Marshall Stiffness, indirect tensile strength and index of retained strength. The results are shown in **Table (7).**

Marshall Test Results:

Marshall Method followed in this study as resistance to plastic flow. Marshall Test specimen prepared and bulk density, percent of air voids, stability, flow and Marshall Stiffness were founded for each prepared specimen, using ASTM methods and specification **Figure (1)** shows the influence of percentage of coarse aggregate crushing on bulk specific gravity, % air voids and voids in mineral aggregate. The results show that, as percent of crushing increases, the bulk density increases (slightly) while air voids and voids in mineral aggregate decreases, that is because of the surface area will increase with increases of % of crushing then the interlock increases and the bulk density increases and the % of air voids and % of mineral filler will decreases.

Figure (2) shows the influence of percentage of crushing on Marshall Stability, Marshall Flow and Marshall Stiffness (represents the value conducted by divided Marshall Stability to Marshal Flow). These curves indicate that Marshall Stability and stiffness increases while Marshall Flow decreases with increasing of percentage of crushing of coarse aggregate (that is because of the interlock and bonding increase with increasing of % of crushing of coarse aggregate).

Indirect Tensile Strength Results:

Indirect tensile test were performed to examine the influence of percentage of crushing of coarse aggregate on the low temperature cracking of asphalt concrete pavements. The effect of percentage of crushing on I.T.S at 25 °C test temperature is shown in **Figure (3).**

As shown in **Figure (3),** ITS increases with increasing of % of crushing of coarse aggregate.

Index of retained strength:

The determination of index of retained strength for several mixes with different percentage of crushing of coarse aggregate depends on Marshall Test procedure. **Figure (4)** shows the index of retained strength values for different values of percentage of crushing of coarse aggregate, this curve indicate that I.R.S increases with increasing of percentage of crushing.

Conclusions

Within the limitations of materials and test program used in this work, the following are concluded:

a- As percentage of crushing of coarse aggregate increases:

1. Bulk density of asphaltic concrete increases slightly,
2. percentage of air voids decreases,
3. percentage of VMA decreases,
4. Marshall stability increases,
5. Marshall flow decreases,
6. Marshall stiffness increases
7. Index of retained strength increases.
8. Indirect tensile strength increases.

b- The mixtures with 40% fractured coarse aggregate accommodate the requirements of Iraqi specification of roads and bridges (SCRB 2003).

Recommendations

- The main recommendation is to study the relationship between the degree of crushing of coarse aggregate accommodate SHRP specification on the properties of asphalt concrete mixtures.

- The second recommendation is to study the influence of surface area of aggregate on performance of asphalt concrete mixtures.

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Table (1): The Physical Properties of Asphalt Cement Type

Property	Unit	Asphalt Cement grade (40-50)	SCRB Specifications
1. Penetration on (25 °C, 100 gm, 5 sec.)	1/10 mm	42	40-50
2. Ductility (25 °C, 5 cm/min)	Cm	175	>100
3. Softening point	°C	52	---
4. Flash point	°C	273	>232
5. Specific gravity at 25 °C	---	1.04	---
After thin film oven test			
Retained Penetration, % of Original	%	79	>52
Ductility of residue	Cm	105	>25
Loss in weight (163 °C, 50 gm, 5 hrs)	%	0.183	---

Table (2): Selected gradation of aggregate, SCRB specification requirements and restricted zone suggested by SUPERPAVE
For 12.5 mm Normal Size

Sieve (mm)	Percent Passing of Available Aggregate	SCRB[1] Specification requirements	Restricted zone by SUPERPAVE[2]
19	100	100	---
12.5	95	90-100	---
9.5	83	76-90	---
4.75	55	44-74	---
2.36	40	28-58	39.1
1.18	---	---	25.6-31.6
0.60	---	---	19.1-23.1
0.30	15	5-21	15.5
0.075	8	4-10	---
% of Asphalt Cement	5	4-6	---

1. SCRB, 2003.
2. Asphalt Institute (SP-2), 2000.

Table (3): Chemical Composition of Nibaee aggregate

Chemical compound	Results %
L. O. I	6.55
Si O2	82.52
Ca O	5.37
Mg O	0.78
SO3	2.7
Fe2 O3	0.69
AL2 O3	0.48
Total	99.09
Mineral composition	
Quartz	80.03
Calcite	10.92

Table (4): Physical properties of Nibaee Aggregate

Property	Coarse Aggregate	Fine Aggregate
Bulk specific Gravity	2.64	2.67
Apparent Specific Gravity	2.695	2.701
Percent water Absorption	0.483	0.692

Table (5): Physical Properties of Mineral Filler (limestone dust)

Property	Test Method	Result	SCRB Specification
Passing sieve No. 200, %	---	100	100
Specific gravity	ASTM C128	2.79	---
Plasticity index	AASHTO T90	1.5	≤ 4

Table (6): Experimental Plan

Mix no.	% of crushing	Applied tests		
		Marshall test	Indirect Tensile Strength	Index of retained Strength
1	0	#		
2	0			#
3	0		#	
4	40	#		
5	40			#
6	40		#	
7	70	#		
8	70			#
9	70		#	
10	100	#		
11	100			#
12	100		#	

Table (7): The Main Properties Results of Different Mixes

Mix No.	Marshall test results at 60 °c						Indirect tensile strength, Kpa	Index of retained strength, %
	Bulk density gm/cm3	Air voids, %	V.M.A, %	Stability, KN	Flow, mm	Marshall stiffness, KN/mm		
1	2.403	3.5	14.56	8.5	3.9	2.179		
2							25	
3								75
4	2.415	3.0	14.14	9.3	3.5	2.657		
5							30	
6								78
7	2.430	2.4	13.60	10.4	3	3.467		
8							31	
9								81
10	2.455	1.4	12.72	10.8	2.7	4.00		
11							32	
12								83

Note: each number represent the average of three spacemen result.

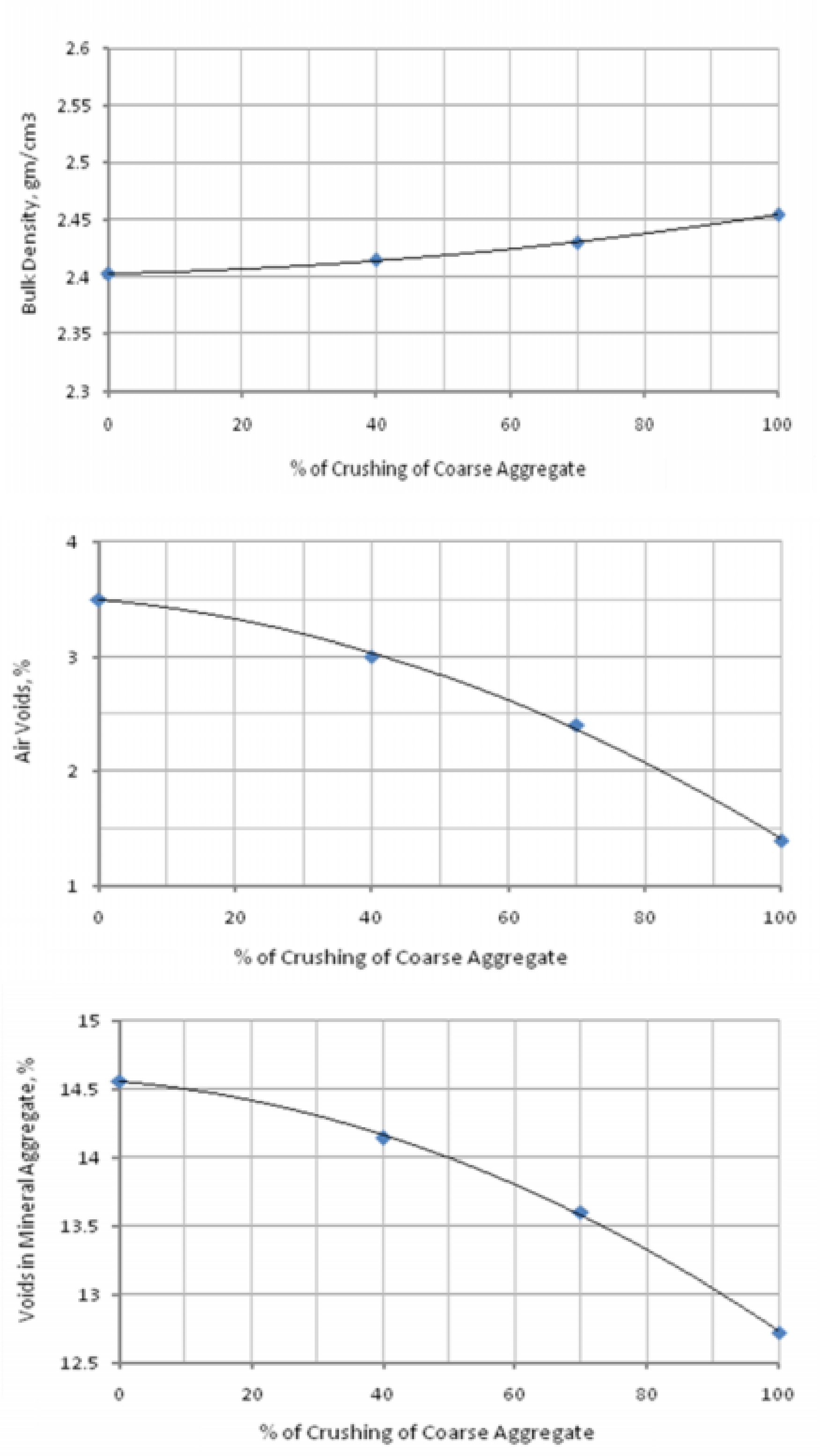

Fig. (1) Influence of degree of crushing on % of Air voids, % VMA and Bulk density.

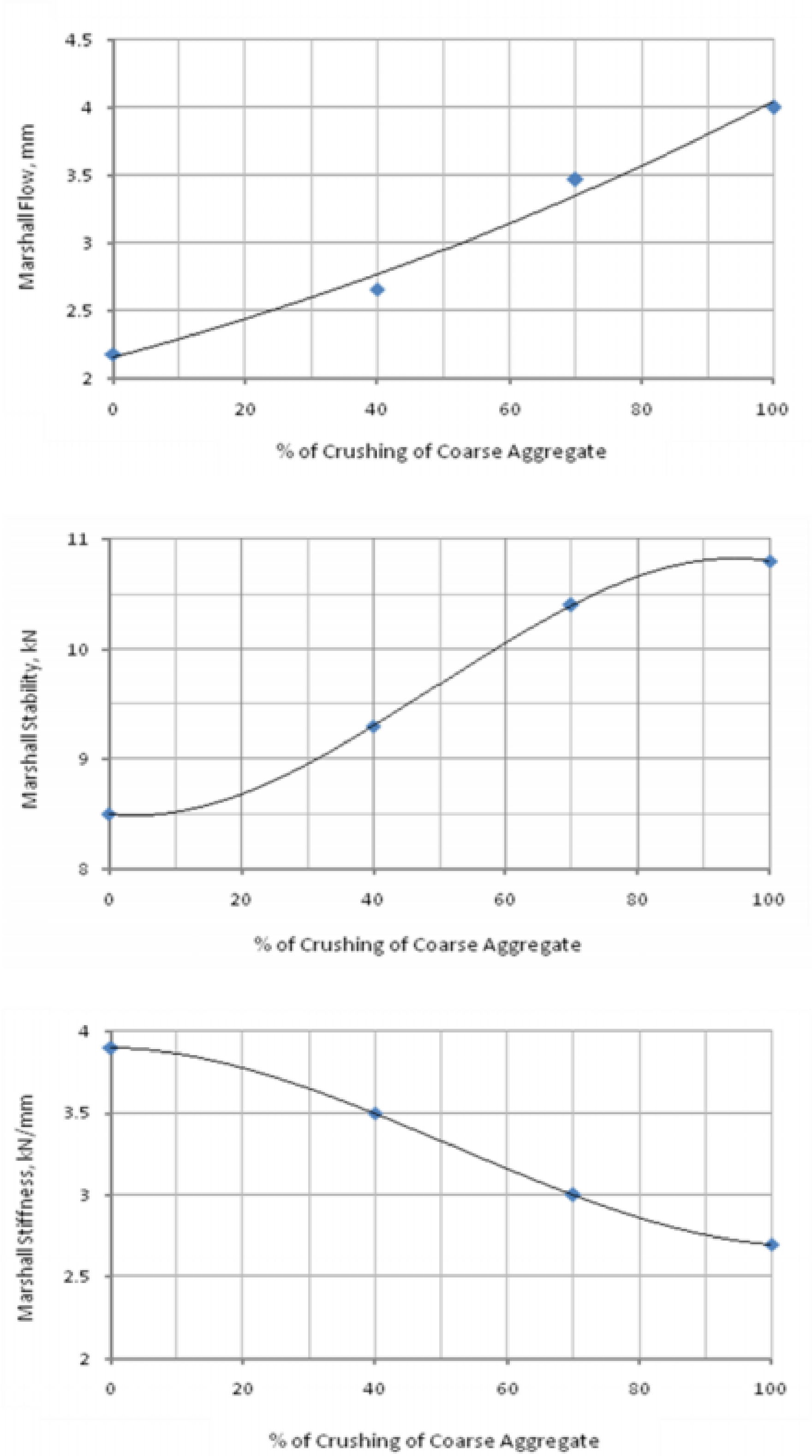

Fig. (2) Influence of degree of Crushing on Marshall Test Results

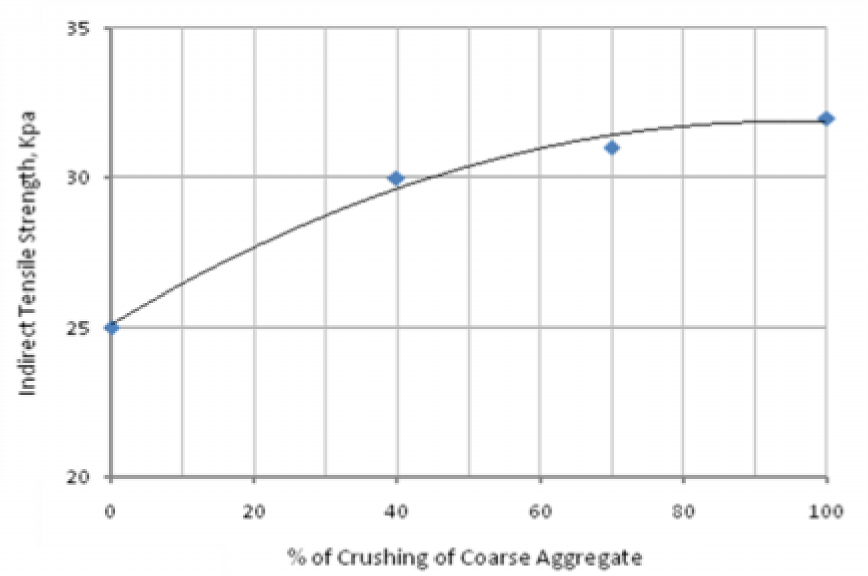

Fig. (3) Influence of degree of crushing on I.T.S at 25 c

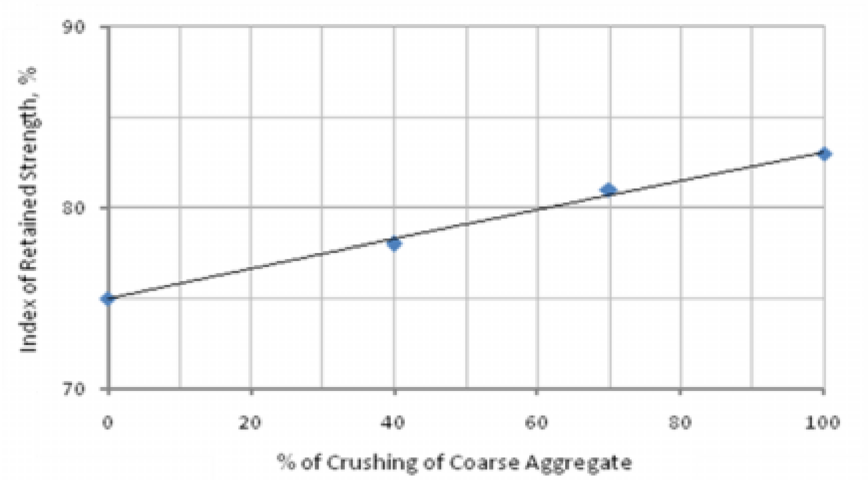

Fig. (4) Influence of degree of crushing on Index of retained strength