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MEASURING AND EVALUATING MODULUS OF ELASTICITY OF ASPHALT MIXTURES USING PLASTOMETER

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الملخص العربي

قياس وتقييم معامل المرونة للمخلوطات الأسفلتية بإستعمال بلاستوميتر رادونسكى

تعتبر الاختبارات المعملية التقليدية المستخدمة فى حساب معامل المرونة للخلطات الأسفلتية مكلفة ومعقدة فى مراحل إجرائها، ويضاف إلى ذلك أن نتائجها ربما تكون مختلفة. ولقد توصل رادونسكى وهو عالم روسى إلى عمل جهاز بسيط استخدمه فى حساب معامل المرونة للمخلوطات الأسفلتية ويسمى (بلاستوميتر) وهذا الجهاز لم يتم تجربته أو استخدامه خارج روسيا.

هذا البحث يهدف إلى التحقق من ما إذا كانت قيم معامل المرونة للخلطات الأسفلتية والمحسوبة من نتائج اختبار البلاستوميتر تعتبر معقولة ومتوافقة مع تلك القيم المحسوبة من الاختبارات المعمول بها حاليا أم لا. كما يهدف البحث أيضا إلى ايجاد علاقات ما بين الطرق المختلفة المستخدمة فى حساب قيم معامل المرونة للخلطات الأسفلتية والقيم المحسوبة من اختبار البلاستوميتر إن أمكن ذلك.

تم إعداد وتصميم دراسة معملية موسعة علي مرحلتين كان هدف كل مرحلة تحقيق أحد أهداف الدراسة. ففى المرحلة الأولى تم تصنيع جهاز البلاستوميتر. ولتجربة استخدام الجهاز المصنع (البلاستوميتر) لحساب قيم معامل المرونة تم اختبار خلطة مرجعية. ولقد تم حساب قيم معامل المرونة للخلطة المرجعية فى درجات حرارة الاختبار المختلفة بطريقة (فان-دار بول) المقبول والمعتاد استخدامها فى ذلك وقورنت نتائجها بما حصلنا عليه من اختبار البلاستوميتر ووجد أن هناك توافق جيد بين الطريقتين وكذلك علاقة قوية بينهما.

ولتحقيق الهدف الثانى من البحث تم عمل المرحلة الثانية وفيها أعد برنامج معملى مفصل يتضمن إعداد خلطات أسفلتية لها ظروف مختلفة من حيث التدرج وطريقة الخلط ودرجة حرارة الاختبار. أجرى اختبار البلاستوميتر على كل هذه الخلطات وتم حساب قيم معامل المرونة لها. وأجريت كذلك بعض الاختبارات المختلفة التى تستخدم فى حساب معامل المرونة علي هذه الخلطات. وبعد حساب قيم معامل المرونة بالطرق المختلفة تم دراسة العلاقة بين قيم المعاملات الناتجة من الطرق المختلفة مع تلك الناتجة من اختبار البلاستوميتر بصفة أساسية.

وبتحليل نتائج البحث وجد أن قيم معامل المرونة الناتجة من اختبار البلاستوميتر تتوافق مع ذات القيم المحسوبة بطريقة (فان - دار بول). وايضا وجد أن الخلطات الأسفلتية ذات التدرجات الأخشن تحقق قيم معامل مرونة أعلى من الخلطات ذات التدرجات الأنعم. وأن عند درجة حرارة الاختبار لها تأثير واضح على قيم معامل المرونة. وجد أن طرق الخلط غير التقليدية خاصة طريقة الفصل المتعاقب تؤثر فى قيم معامل المرونة للخلطات الأسفلتية.

ABSTRACT

It is of a great impc.tance in the design of asphalt mixtures to know their modulus of elasticity. The common laboratory tests used for measuring the resilient modulus are very sophisticated and complicated. Radonesky (A Russian pavement material researcher) suggested and prepared a simple device called "plastometer" to be used in measuring modulus of elasticity of asphalt mixtures. This study aims at investigating the use of this

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device (plastometer) for measuring modulus of elasticity of asphalt mixes in Egypt. The study aims also to search the different factors affecting the values of modulus of elasticity as well as finding the possible relationships between the different traditional methods used to determine this modulus and the plastometer test procedure. These methods include Van-der Poel, dynamic stability, and Marshall stiffness. To achieve the study objectives a comprehensive experimental program is carried out on limestone-asphalt mix under different conditions including mix gradation, mixing procedure, and testing temperature. The experimental program passes through two main phases. The first phase is conducted on one mix having the same material properties and mixing procedure at different testing temperatures to check the validity of using plastometer in measuring modulus of elasticity for asphalt mixes. While, the second phase is directed to find possible relations between the results of the different methods used to determine the modulus of elasticity.

Based on the study results, it can be concluded that plastometer test results can be used satisfactorily in determining modulus of elasticity of asphalt mixtures. Valuable relationships are found between the different methods used in calculating modulus of elasticity and the plastometer method.

INTRODUCTION

The existing trends of designing flexible pavements depend on numerical analysis of layered systems which includes study of stresses, strains and deflections [1,2]. This necessitates the use of resilient modulus. Resilient modulus is used by AASHTO to characterize the roadbed soil as well as all pavement layers for design purposes. Resilient modulus can be measured in laboratory using repeated load test or can be estimated from deflection basins using back calculation procedures [3,4]. Resilient modulus in a simple term is the modulus of elasticity when the theory of elasticity is applied. Radonesky [5,6] suggested and prepared a simple device for measuring the modulus of elasticity of asphalt concrete mixtures. Radonesky device and procedure were approved by Russian specifications. But this device is still under investigation in other countries.

The conventional laboratory tests used for measuring the resilient modulus are very sophisticated and eomplicated. In addition, there is a considerable difference between their results and those obtained using back calculation procedures. Simple procedure was suggested in Russia by Radonesky [5,6] to measure modulus of elasticity of asphalt mixtures and still under investigation. So, it is of a great importance to check Radonesky procedure to find a simple method for calculating the modulus of elasticity.

This study aims at investigating the use of the simple device prepared by Radonesky for measuring the modulus of elasticity of asphalt mixtures in Egypt. Another objective is to evaluate the factors affecting the values of modulus of elasticity. A third objective is to find the possible correlations between values of modulus of elasticity calculated using this plastometer test and those obtained from other conventional methods. These methods include, Van-der Poel, dynamic stability based on Wheel Tracking Test (WTT) results, and Marshall stiffness calculated from the Marshall test procedure.

STUDY METHODOLOGY

To achieve the study objectives, the following steps are made: manufacturing Radonsky's device including the testing tools and mould of test specimens, selecting and collecting suitable types of different materials required for preparing the investigated asphalt mixtures, choosing the different variables for the investigated mixtures and testing as well as designing the required testing program, preparing asphalt mixtures for testing. measuring the modulus of elasticity using Radonesky device and other conventional methods, comparing the results of both Radonesky test and the other selected methods. deducing possible correlations between modulus of elasticity determined by the plastometer device test and those obtained from other methods.

EXPERIMENTAL PROGRAM

The experimental program is designed to include the following two phases.

1- Pilot Study: The pilot study represents the first stage of the experimental program. As a starting point, a reference mix is considered. This reference mix is composed of limestone as coarse aggregate, sand as fine aggregate, and limestone dust as mineral filler. The gradation of this reference mix similar to the standard gradation (4C) defined by the Egyptian Specifications. The plastometer test is conducted on asphalt concrete mixes representing the reference mix. These mixes are prepared at the optimum asphalt content (OAC) and unit weight resulting from the Marshall mix design method. To investigate the effect of testing temperature on the values of modulus of elasticity, three testing temperatures (20°, 40°, and 60°C) are considered when conducting the plastometer test on the reference mix to simulate the climatic conditions in Egypt.

2- Studing the Relations between Different Procedures used for Measuring Modulus of Elasticity

The objective of the second stage of the experimental program is to study the relations between different methods used for measuring modulus of elasticity. These methods are the plastometer test, Van-der Poel, dynamic stability based on wheel tracking test, and Marshall stiffness. This stage is achieved and checked using different mix properties and characteristics such as gradation, mixing procedure, and testing temperature. The selected gradations are in the range of the Standard Gradations (3B, 4C, 5B, and 6B). These gradations are shown in Table (1). Mixing procedure is another factor that may affect asphalt concrete mix behavior. To investigate the effect of mixing procedure on the values of the modulus of elasticity, three mixing procedures are used. These mixing procedures are: traditional (TRP), two stage (TSP), and separate-successive (SSP) mixing procedures. In the traditional method, the normal procedure of the Marshall mix design is followed. In the TSP method, the coarse and fine aggregates are mixed together, asphalt is mixed with mineral filler, and then the two mixtures are added together. In the SSP method, small portion of the asphalt quantity say A_1 (about 15% of the OAC) is mixed with coarse and fine aggregates, whereas the rest of the asphalt quantity A_2 (about 85% of the OAC) is mixed with mineral filler and the two mixtures are then added together [7, 8]. Three testing temperatures are used for the different mixtures (20°, 40° and 60°C).

TESTING: Two groups of tests are applied. The first group is the acceptance tests. They are conducted to identify the different properties of materials used. While the second type is the main tests used to measure the modulus of elasticity of different investigated mixes. The Plastometer test is conducted for 36 asphalt mixtures with different properties. Mix stiffness for the previous asphalt mixtures is also calculated using Van-der Poel method. Dynamic stability of asphalt mixtures at different conditions are determined through applying wheel tracking tests on these mixtures. Marshall stiffness values of the 12 asphalt mixtures are also calculated through applying Marshall test on these mixtures.

PLASTOMETER TEST METHOD

This section presents all needed information about Radonesky apparatus (plastometer). Complete manufacturing of test device, test samples preparation procedure and testing process are thoroughly explained. The procedure of determining the modulus of elasticity using Plastometer test results is explained in the following sub-sections:

Manufacturing Process of the Plastometer Apparatus: Because the plastometer apparatus is not known test, its device is not available for sale. Therefore using it in Egypt required manufacturing of this device locally. The manufacturing is conducted by E. Abu Elmagd workshop, Industrial City, Zagazig, Egypt under tight supervision of the researcher. The manufactured parts include testing device, sample mould, and auxiliary tools (see Figures (1, 2)).. The manufactured plastometer device is calibrated using asphalt mixes similar to that tested in Russia. The calibration process showed a high degree of reliability of the manufactured device.

Preparation of Test Specimen: About 620 gm of asphalt aggregate mixture is used to produce each test specimen. The OAC determined using Marshall mix design method is used as a base to prepare Plastometer test specimens. The aggregate blend composed of coarse and fine aggregates, and limestone dust. Weights of every part of the aggregate and asphalt are determined according to the mix gradation and the specified sample weight according to the mould volume. To prepare a test specimen, asphalt and aggregate are heated to about 150°C, then mixed using mixing spoon in a pan. At the same time the sample mould is heated to about 100°C before pouring the mixture to eliminate adverse effects on mixing temperature. After putting the mixture in the sample mould, a solid steel piece with dimensions 4 x 4 x 16 cm is then placed over the mix and all are compacted using a static compression testing machine. The other solid steel part with dimensions 4 x 8 x 16 cm is used to pull the specimen out of the mould after supporting it on the two supporting beams. The specimen is left for 24 hours before testing.

Testing Process: In the beginning of the testing process, the specimen is heated in an oven to about 5°C lower than the test temperature to remove any humidity and to insure a homogenous distribution of temperature inside the specimen during the test. Then, the specimen is placed for 30 minutes in a water bath at a temperature equals to the test temperature, three testing temperatures are used (20°, 40°, and 60°C), to simulate different climatic conditions.

The specimen is then placed on the Plastometer testing device. A suitable weight specified by Radonesky is placed on the plastometer to compress the test sample. This weight depends on the proposed test temperature. It is about 3 kg for a 60°C test temperature. It should be increased by 1 kg for each decrease of 20°C decrease in test temperature. Deflection of the specimen is recorded every one minute using a dial gauge. The readings of the first five minutes are disregarded. The test is continued for 10 minutes. After that, the sample is taken out from the plastometer apparatus. For a high test temperature, a water bath is used to maintain the temperature of the specimen during the whole time of the test.

Calculation Process: Based on data recorded during the test of the specimen using Plastometer, Radonesky [5, 6] gives a formula to evaluate the rheological characteristics (viscosity, plasticity and modulus of elasticity) for the asphalt concrete mix as follows:

$$\eta = Q\Phi\,(T_{600} - T_{300}) / (f_{600} - f_{300}) = Q\Phi\,\Delta T / (\Delta f) \qquad (1)$$

Where: η = Viscosity, poise; Q = Applied load, kg; Φ = A coefficient depends on specimen dimensions; ΔT= Difference in time for the time interval used in calculations (interval is 5 minutes starting after first 5 minutes from the start of the test); and Δf= Difference in dial gauge readings (deflection in the specimen after 5, 10 minutes), cm.

Radonseky gives a simplified form for the above equation based on specimen dimensions of 4 x 4 x 16cm. This formula is as follows [5, 6]:

$$\eta = (0.804 \times 10^6 Q) / \Delta f \quad (2)$$

The plasticity for asphalt concrete mix, P, is given by the following formula:

$$P = 1 - \log \eta / 18 \quad (3)$$

Finally, the dynamic modulus of elasticity (E) in kg/cm^2 is given by the following formula: $\log E = 2.2 (1\text{-}P) + 3$ (4)

This modulus represents a dynamie modulus of elasticity corresponding to a loading time of 0.02 second for the asphalt concrete mix.

MARSHALL TEST: Marshall test method, as described in ASTM and Egyptian specifications is conduced to find the characteristics of asphalt mixture used for calculating the modulus of elasticity.

Marshall Mix Stiffness: The stiffness of asphalt concrete mixtures are calculated by Brown and Cooper [9] using the formula: $S_m = (S.d) / (t.d.f) = (q/t)$ (5)

WHEEL TRACKING TEST: The wheel tracking test (WTT) is a simulative rutting test. developed by the British Road Research Laboratory [10].

The tracking rate (TR), is determined from the last third of the deformation/time curve, (from 30-45 minutes) which is approximately linear. A stress level of 5.3 kg/cm^2 (75 psi) and a test temperature of 60°C are considered as standard test conditions in Egypt. as suggested by Rolt [11].

Wheel Tracking Test Results: The WTT results were represented by three different parameters, as follows:

a- $TR = 10.16 \times 10^{-2} (TD_{45} - TD_{30})$ (6)

Where: TR = Conventional tracking rate, mm/hour; TD_{30}= Track depth after 30 min., 0.001 in., and TD_{45}= Track depth after 45 min., 0.001 in.

b- $CTR = 1.524\, b$ (7)

Where: CTR = Comprehensive tracking rate, mm/hour; and b = Slope of track depth/time regression line, 0.001 in./min.

c- Dynamic Stability $D.S = N_{60} / (CTR)$ (8)

Where: D.S = Number of wheel passes that produces a rut depth of 1 mm. N_{60}= Number of passes per hour = 2520 (60 min, about 42 pass/min). This leads to the final formula:

$$D.S = 2520 / (CTR) \quad (9)$$

More details concerning the WTT procedure and data treatment is can be found in reference [12].

RESULTS AND DISCUSSION

Firstly, plastometer test results of the reference mix were analyzed and discussed to give a decision about the use of plastometer test in measuring the modulus of elasticity for the asphalt concrete mixtures. The OAC and unit weight of the plastometer samples were those resulting from the Marshall test of the reference mix. The analysis includes time-deflection analysis and the reliability of using the plastometer test in measuring the modulus of elasticity of asphalt concrete mixes. Secondly, general plastometer test results were discussed and analyzed. This includes deflection values versus time application of plastometer test to evaluate the behavior of the asphalt mix specimens during test. The OAC and unit weight of the plastometer specimens were those resulting from Marshall test of the investigated mixtures. Table (2) illustrates Marshall characteristics of the investigated mixes. The effect of different factors on the values of modulus of elasticity of asphalt concrete mixtures are discussed. These factors include mix gradation, mixing procedure, and testing temperature. Finally, several correlations between the different methods used to evaluate the modulus of elasticity of asphalt concrete mixtures were deduced. These methods include the plastometer test procedure, Van-der Poel mix stiffness method, dynamic stability based on wheel tracking test, and mix stiffness based on Marshall test.

ANALYSIS OF PLASTOMETER TEST RESULTS VERSUS THE REFERENCE MIX

Time Deflection Analysis of Tested Specimens: Deflection of the test specimens occurs as soon as loading of the specimen in the plastometer equipment begins. The value of deflection increases as the time increases achieving the highest value at the end of the test time (10 minutes). Figure (3) describes the relationship between deflection and time for different test conditions. The figure shows that deflection of the specimen passes through three stages. The time interval (1-3 minutes) describes the first stage. In this stage the deflection increases with an increasing rate indicating high straining behavior of the test specimen. The second stage describes the behavior of asphalt mixture in the time interval (3-5 minutes). In this stage, the rate of deflection increase becomes with lower rate but it is still high and unstable. The last stage lies between (5 and 10 minutes). In this stage, it is noticed that the rate of increase of deflection becomes stable and achieves the lowest values.

Studying the effect of testing temperature on the deflection-time relation showed that the deflection values increase as the test temperature increases and the maximum is achieved at the highest temperature used (60°C). Furthermore, rates of different stages of time-deflection relation increase with increasing test temperature. In the first stage, this rate increases from 0.006 to 0.0085 mm/min as testing temperature increases from 20° to 40°C and becomes 0.0105 mm/min at 60°C. However, this rate is 0.00285 mm/min in the second stage at 20°C and reaches 0.0057 and 0.0066 mm/min at testing temperatures of 40°C and 60°C, respectively. The lowest rates are achieved in the last stage. This rate is 0.00086 mm/min for testing temperature of 20°C and it increases from 0.00166 to 0.0023 mm/min respectively for testing temperatures 40°C and 60°C.

Evaluation of Modulus of Elasticity: Modulus of elasticity of the reference mix at different testing temperatures is calculated and its values are shown in Table (3). The values of modulus of elasticity decrease as the testing temperature increases achieving the highest value at 20°C (12533 kg/cm^2) and decreases to about 90% of its original value at

40°C. The modulus of elasticity achieves its lowest value at 60°C (10466 kg/cm^2) which is approximately 83% of that achieved at 20°C. Based on these results it is obvious that the testing temperature has a considerable effect on the values of the modulus of elasticity.

Validity of the Plastometer Test Results: To check the validity of the plastometer test results, the stiffness of asphalt concrete mixes considered in the pilot study are calculated using Van-der Poel method.The relationship between modulus of elasticity measured using plastometer test results and the stiffness of asphalt concrete mix using Van-der Poel method is also found. Good relation is found between the two methods. The following equation is obtained for the available points:

$$E = 0.0311 * S_{mix} + 10710 \qquad (R^2 \cong 0.92)$$

Where: E = Modulus of elasticity calculated using plastometer test results, kg/cm^2, and:

S_{mix}= Stiffness of asphalt concrete mix using Van-der Poel method, kg/cm^2.

It is of great consideration to notice that the previous relation will be investigated for several asphalt concrete mix samples.

Reviewing the analysis of the reference mix results, it can be concluded that plastometer test results can be considered satisfactory and convenient and give the same trend as other methods. Thus, it can be said that the use of the plastometer test in measuring the modulus of elasticity is considered convenient. Other checking is made during the study program.

ANALYSIS OF THE PLASTOMETER TEST RESULTS

Time-Deflection Analysis of Tested Specimens: Tables (4) through (6) show the time-deflection relationship of different asphalt concrete mixtures. These tables show the same trend obtained for the reference mix. The time-deflection relationship are still divided to three stages according to the rate of deflection increase as previously explained. It is worth mentioning, that the asphalt mixtures having different gradations, mixing procedures, and testing temperatures, having a rate of deflection increase ranging between 0.08 and 0.12 mm/min. in the first stage. This rate ranges between 0.02 and 0.07 mm/min and 0.006 and 0.03 mm/min respectively for the other stages.

The results of studying the effect of mix gradation on deflection behavior of plastometer specimens, show that the coarser graded mixture G_1 achieves the lowest deflection, while the finer graded mixture G_4 achieves the highest deflection values at all mixing procedures and testing temperatures. At 20°C temperature, it is also noticed that the minimum difference between the deflection values of both coarser and finer graded mixtures ranges between 0.06 and 0.10 mm at the beginning of the test. This difference becomes between 0.08 and 0.12 mm at the end of the test. The effect of mix gradation on the plastometer test results is clear at the lowest test temperature (20°C). The coarser gradation G_1 achieves deflection values lower by 0.02 to 0.08 mm than that of the G_2 mixture. While the mixtures of gradations from G_2 to G_4 exhibit small difference in deflection values ranging between 0.03 and 0.06 mm. This effect decreases as test temperature increases. This indicates that the coarser graded mixture has a higher resistance to rutting than that of the finer graded mixture. Furthermore, the coarser graded mixture achieves the highest modulus of elasticity values. This may be due to the increase of the sample unit weight and the decrease in its voids ratio, and the lower voids in mineral aggregate, which lead to a better frictional and interlocking resistance.

Also table (5) shows that the effect of mixing procedure on the deflection values depends on testing temperature and mixture gradation. The separate successive mixing procedure (SSP) achieves the lowest values of deflection at all mixture gradations and testing temperatures. This effect is high at lower test temperature and decreases as temperature increases. At the lower test temperature (20°C) SSP achieves lower deflection values than those obtained from the traditional mixing procedure (TRP) by values ranging between 0.04 and 0.07 mm and between 0.006 and 0.03 mm for the two-stage mixing procedure (TSP). This difference decreases with increasing test temperature and reaches a range between 0.007 to 0.027 mm and 0.003 to 0.021 mm for the TRP and TSP respectively at 40°C. A continuous decrease of the effect of mixing procedure is noticed with increasing testing temperature up to 60°C. TSP achieves approximately the same effect as SSP while TRP gives a slightly higher deflection values ranges between 0 and 0.019 mm for all mixture gradations.

The effect of test temperature on the recorded deflection are presented in tables (4) through (6). It is found that the higher the test temperature the higher the deflection values. This in turn reduces the modulus of elasticity of the asphalt concrete mixture. A testing temperature of 20°C gives the lowest deflection values, while the highest values are achieved at 60°C. The difference between deflection values for a testing temperature of 20°C is found in the range of 0.032 to 0.051 mm. These differences are in the range of 0.071 to 0.1 mm and 0.09 to 0.154 mm for testing temperatures of 40°C and 60°C respectively.

Factors Affecting the Modulus of Elasticity of Asphalt Concrete Mixtures

The values of modulus of elasticity of the investigated mixtures are calculated based on the determined values for the deflection differences (Δf) using the 1 through 4. The resulting values of the modulus of elasticity are presented in Tables (7) through (9).

The effects of mix gradation, mixing procedure, and testing temperature on the calculated values of modulus of elasticity are studied.

Effect of Mix Gradation: The coarser graded mixture G_1 achieves maximum values of the modulus of elasticity followed by those of gradation G_2. The finer graded mixture achieves minimum values of the modulus of elasticity. The difference between the modulus of elasticity values of coarser and finer graded mixtures, at all testing temperatures and for all mixing procedures is found in a small range of 413 to 670 kg/cm^2 (i.e. about 3% to 6%). This difference may be due to the higher unit weight, lower asphalt content and/or air voids of the coarse graded mixtures

Effect of Mixing Procedure: The effect of mixing procedure on the values of modulus of elasticity of the asphalt concrete mixes can be evaluated by analyzing the data shown in tables (7) through (9). The tables show that the SSP achieves the highest values of the modulus of elasticity followed by the TSP. The TRP achieves the lowest values. This is occurred for all testing temperatures, discarding finer gradation at 60°C temperature. The SSP achieves slightly lower values of modulus of elasticity. Table (6) shows the difference between the values of modulus of elasticity for the coarser gradation G_1 and the finer mix gradation G_4 for all mixing procedures and at all testing temperatures. This table shows that, at the lowest test temperature of 20°C, the SSP achieves the highest difference in the values of modulus of elasticity than that of the TRP. This difference is 185 kg/cm^2 (1.44% of the modulus of elasticity for G_1 mixture) and 189 kg/cm^2 (1.54% of the modulus of elasticity for G_4 mixture). On the other hand, the lowest difference in the modulus of elasticity values is found between the SSP and TSP (33 kg/cm^2 equivalent to 0.27% of the modulus of elasticity).

Effect of Test Temperature: The effect of testing temperature on modulus of elasticity values can be detected from Figures (4) through (6) and Table (10). The figures show that the values of modulus of elasticity decrease with increasing test temperature. At the lower test temperature (20°C), the modulus of elasticity for all mix gradations and mixing procedures achieves the maximum values. It can be concluded that mixing procedure has a great effect on modulus of elasticity values at small testing temperature. So, other methods of mixing than the TRP is preferable to use in cold climate countries.

CORRELATION BETWEEN MODULUS OF ELASTICITY AND VAN-DER POEL MIX STIFFNESS VALUES

The modulus of elasticity is calculated based on deflection values measured during the plastometer test, and results are previously shown in Tables (7) through (9). Stiffness values of asphalt concrete mixtures are obtained using Van-der Poel method. The resulting values are presented in Table (11). One of the objectives of this research study is to investigate the correlation between the values of modulus of elasticity (E) measured using plastometer test and the mix stiffness (S_{mix}) calculated by using van-der Poel method. Figure (7) illustrates the obtained relations at different testing temperatures. The figure shows that the mixes of higher values of E achieves a good correlation between E and S_{mix} than that of the lower values. It is noticed that the relation improves with the increasing of testing temperatures. These relations can be expressed using linear equations as follows:

- At testing temperature of 20°C: $E = 0.015 \times S_{mix} + 11700$ ($R^2 = 0.86$)
- At testing temperature of 40°C: $E = 0.08 \times S_{mix} + 10600$ ($R^2 = 0.97$)
- At testing temperature of 60°C: $E = 0.72 \times S_{mix} + 9700$ ($R^2 = 0.99$)

CORRELATION BETWEEN MODULUS OF ELASTICITY AND DYNAMIC STABILITY

The wheel tracking test parameters are calculated. These parameters include Tracking Rate (TR), Comprehensive Tracking Rate (CTR), and Dynamic Stability (D.S). The results of these calculations are shown in Table (12).

Based on the modulus of elasticity (E) values of the investigated asphalt concrete mixes measured by the plastometer test, shown in Tables (7) through (9), and dynamic stability (D.S) values based on wheel tracking test, shown in Table (12), the relationship between E and D.S values is determined. The following relationship is obtained:

$E = 0.98 \times D.S + 5760$ ($R^2 = 0.84$)

This relationship shown in Figure (8), is the best correlation in the covered range of tests. The figure indicates that as the dynamic stability values increase, modulus of elasticity also increases.

CORRELATION BETWEEN MODULUS OF ELASTCIITY AND MARSHALL STIFFNESS

Based on Marshall test results, Marshall stiffness values are calculated. The relationship between Marshall stiffness (S_m) and modulus of elasticity measured using the plastometer test (E) is investigated. The resulting relationship is shown in Figure (9). The following equation is deduced from the correlation in the figure:

$$E = 6.43 \times S_m + 6130 \qquad (R^2 = 0.72)$$

This relationship is found to be significant (α = 0.00054). This indicates a convenient correlation between the modulus of elasticity and Marshall stiffness. It is also obvious that as the Marshall stiffness increases the modulus of elasticity increases and vice versea.

CONCLUSIONS AND RECOMENDATIONS

Analyzing the results of this study, the following conclusions and recommendations may be obtained:

1- Reasonable values for the modulus of elasticity of asphalt concrete mixtures can be achieved using the plastometer test.

2- The values of the modulus of elasticity of asphalt concrete mixture depend on the mix gradation, higher values are obtained for coarser gradations.

3- The separate successive mixing procedure (SSP) achieves higher values of modulus of elasticity of asphalt concrete mixtures.

4- The combined effect of testing temperature and mixing procedure on the modulii of elasticity values is variable.

5- Good correlation is found between the values of the modulus of elasticity (E) calculated using the plastometer test results and values of mix stiffness (S_{mix}) determined using the Van-der Poel method. This correlation is given by the following equations:

- At testing temperature of 20°C: $E = 0.015 \times S_{mix} + 11700$ ($R^2 = 0.86$)
- At testing temperature of 40°C: $E = 0.08 \times S_{mix} + 10600$ ($R^2 = 0.97$)
- At testing temperature of 60°C: $E = 0.72 \times S_{mix} + 9700$ ($R^2 = 0.99$)

6- Good correlation is found between the values of modulus of elasticity (E) measured by the plastometer test and dynamic stability (D.S) calculated from the wheel tracking test results. This relation is as follows: $E = 0.98 \times D.S + 5760$ ($R^2 = 0.84$)

7- Reasonable correlation is also found between the values of modulus of elasticity calculated from the plastometer test and mixture stiffness calculated based on Marshall test results (S_m). This relation is given by the equation: $E = 6.43 \times S_m + 6130$ ($R^2 = 0.72$)

8- the plastometer test is a simple and inexpensive test that can be used for measuring the modulus of elasticity of asphalt mixtures in Egypt. This is recommended to be considered as a standard test in the Egyptian specifications.

9- Measuring the modulus of elasticity of sand mixes and similar types of mixes using the plastometer test need to be studied.

10- The use of the modulus of elasticity measured by the plastometer test in the structural design of asphalt pavement is recommended.

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ABBREVIATION:

CTR : Corrected tracking rate.

DS : Dynamic stability

TD : Tracking depth.

TR : Tracking rate.

TRP : Traditional mixing procedure.

TSP : Two-stage mixing procedure.

SSP : Separate successive mixing procedure.

WTT : Wheel tracking test.

Table (1): Selected Mix Gradations and Egyptian Specifications of Gradations.

Sieve size	% passing by weight							
	G1	(3B)	G2	(4C)	G3	(5B)	G4	(6B)
3/4"	100	100	100	80-100	100	100	100	100
1/2"	75.43	75-100	79.54	-	89.98	85-100	96.43	-
3/8"	61.17	60-85	67.95	60-80	80.66	-	89.1	85-100
No. 4	42.07	35-55	52.66	48-65	65.63	65-80	75.01	-
No. 8	30.21	20-35	43.08	35-50	56.01	50-65	65.93	65-80
No. 30	19.75	10-22	28.65	19-30	36.73	25-40	42.63	30-55
No. 50	15.22	6-16	22.30	13-23	28.22	18-30	32.32	20-40
No. 100	7.57	4-12	11.54	7-15	13.86	10-20	15.01	10-25
No. 200	4.35	2-8	6.92	3-8	7.33	3-10	7.89	3-8

G1: Designed gradation for gradation 3B
G2: Designed gradation for gradation 4C
G3: Designed gradation for gradation 5B
G4: Designed gradation for gradation 6B

Table (2): Asphalt Contents Used and Corresponding Marshall Mix Properties.

Mix No.	AC%	γ gm/cm³	Stability		Flow		AV%	VMA%
			lb	kg	0.01"	0.01cm		
25	5	2.407	1950	884.52	8	20.32	3	14
26	5.1	2.406	2425	1099.98	10.6	26.92	3.5	14.8
27	5.3	2.372	2580	1170.23	11.7	29.72	4.5	16.2
28	5.7	2.368	2592	1175.73	12.1	30.734	4.8	16.3
29	4.8	2.393	2235	1013.8	9	22.86	3.5	13.8
30	5	2.395	2631	1193.42	10.9	27.69	4	14.7
31	5.1	2.364	2694	1222	11.8	29.97	4.5	16.1
32	5.5	2.370	2699	1225	12	30.48	4.7	16.1
33	4.7	2.395	2353	106732	9.2	23.37	3.1	13.5
34	4.6	2.398	2775	1258.74	11.2	28.45	4.4	14.5
35	5	2.355	2800	1270.08	11.9	30.23	3.7	15.2
36	5.6	2.371	2815	1276.88	12.2	30.99	4.5	16

Table (3): Rheological Characteristics of the Reference Mix.

Item \ Temp.	Testing temperature, °C		
	20	40	60
Δf	4.3	8.3	11.5
η	964052093	402581204	220645565
P	0.500883305	0.521952583	0.536461377
E	12533	11264	10466

Δf = Deflection difference, 0.001 mm
η = Viscosity, poise
P = Plasticity
E = Modulus of elasticity, kg/cm²

Table (4): Recorded Deflection Values for the Tested Specimens Using Plastometer (Group I, Test Temperature = 20°C).

Deflection, 0.01mm / Time, min	TRP				TSP				SSP			
	1	2	3	4	5	6	7	8	9	10	11	12
1	17	20	24	26	15	17	19	21	10	15	19	20
2	23	27	31	32	22	24	26	26	17	23	27	29
3	27	32	35	36	26	29	30	30	22	28	31	32
4	30	35	38	38	28	32	33	34	25	31	34	35
5	32	37.7	40	40.7	29.2	34	35.5	36.8	26.3	33.5	35.1	36.3
6	33.2	38.5	41.2	41.9	30.1	35.2	36.9	38.3	27.4	34.4	36.2	37.6
7	34.1	39.4	42.3	42.8	31.0	36.1	37.6	39.4	28.2	35.2	37.2	38.4
8	34.7	40.9	43.5	43.7	31.7	37.2	38.3	40.3	28.7	35.9	37.9	39.3
9	35.3	41.7	44.2	44.5	32.3	37.7	39.5	41.0	29.3	36.8	38.6	39.9
10	35.6	42.0	44.8	45.8	32.5	38.2	40.0	41.4	29.5	37.6	39.3	40.8
Δf*	3.6	4.3	4.8	5.1	3.3	4.2	4.5	4.6	3.2	4.1	4.2	4.5

Δf* = Deflection at 10 min – deflection at 5 min.
Four mixtures in each mixing procedure indicate mix gradation (G1 through G4).

Table (5): Recorded Deflection Values for the Tested Specimens Using Plastometer (Group II, Test Temperature = 40°C).

Deflection, 0.01 mm / Time, min	TRP				TSP				SSP			
	13	14	15	16	17	18	19	20	21	22	23	24
1	20	22	26	29	18	20	25	25	15	20	24	24
2	29	29	36	38	28	29	35	35	26	30	34	33
3	36	36	42	44	35	36	42	42	33	37	41	41
4	40	43	47	48	40	42	47	48	39	42	47	46
5	45.2	47.4	51.7	52.5	44.5	46.7	51.2	52.1	43.7	46.9	51	50.1
6	47.7	50.3	54.9	56	47.6	49.2	54.3	55.6	46.2	50.7	54.1	53.2
7	49.1	52.7	57.4	58.5	49.1	51.2	56.5	58.1	47.6	52.6	56.5	55.6
8	50.3	53.6	59.1	60.3	50.3	52.6	58.3	60.2	48.9	54.1	58.3	57.1
9	51.5	54.9	60.5	61.8	51.2	53.9	59.5	61.3	50.2	54.7	59.4	58.9
10	52.6	55.7	61.2	62.5	51.7	54.9	60.4	61.9	50.8	55.0	60.1	59.8
Δf*	7.4	8.3	9.5	10	7.2	8.2	9.2	9.8	7.1	8.1	9.1	9.7

Table (6): Recorded Deflection Values for the Tested Specimens Using Plastometer (Group III, Test Temperature = 60°C).

Deflection, 0.01mm / Time, min	TRP				TSP				SSP			
	25	26	27	28	29	30	31	32	33	34	35	36
1	29	30	36	36	26	30	35	37	24	30	34	36
2	38	43	47	47	37	43	46	48	38	42	45	45
3	44	51	55	56	46	51	54	55	48	50	53	53
4	53	59	60	61	53	58	59	60	55	57	58	58
5	61.5	64.2	63.5	64.5	61.3	64.1	64.2	64.4	61.2	62.5	62.5	63.0
6	65.5	68.1	66.7	69.1	64.3	67.2	67.7	68.6	63.3	65.3	66.8	66.6
7	67.3	71.6	69.5	73.3	66.6	70.1	71.3	72.8	65.9	68.7	70.6	70.6
8	68.8	73.2	73.1	76.1	68.4	72.5	74.6	75.5	67.5	70.9	73.9	73.3
9	69.6	74.3	76.3	78.3	69.8	73.1	76.9	77.7	69.2	72.7	75.6	76.6
10	70.7	75.7	78.1	79.7	70.7	75.5	78.8	79.5	70.3	73.8	77.0	78.4
Δf*	9.2	11.5	14.6	15.2	9.4	11.4	14.6	15.1	9.1	11.3	14.5	15.4

Table (7): Rheological Characteristics of Tested Specimens, Group I, (Test Temperature = 20°C, Q = 5.156 kg).

Mix No.	Δf	η	P	E
1	3.6	11515066.67	0.496596308	12808
2	4.3	964052093	0.500883305	12533
3	4.8	863630000	0.503537348	12366
4	5.1	812828235	0.505000067	12274
5	3.3	1256189091	0.494496943	12945
6	4.2	987005714	0.500315574	12569
7	4.5	921205333	0.501980197	12463
8	9.6	901179130	0.502510493	12430
9	3.2	1295445000	0.493754501	12993
10	4.1	1011079024	0.499734161	12606
11	4.2	987005714	0.500315574	12569
12	4.5	921205333	0.501980197	12463

Δf = Deflection difference, 0.001 mm η = Viscosity, poise
P = Plasticity E = Modulus of elasticity, kg/cm²

Table (8): Rheological Characteristics of Tested Specimens, Group II, (Test Temperature = 40°C, Q = 4.156 kg).

Mix. No.	Δf	η	P	E
13	7.4	451543783	0.51918334	11423
14	8.3	402581204	0.521952583	11264
15	9.5	351728842	0.525210667	11079
16	10	334142400	0.526448245	11010
17	7.2	464086666	0.518522272	11461
18	8.2	407490731	0.521660125	11281
19	9.2	363198260	0.524436457	11123
20	9.8	340961632	0.525960804	11037
21	7.1	470623098	0.51818482	11481
22	8.1	412521481	0.521364079	11297
23	9.1	367189450	0.524172766	11138
24	9.7	344476701	0.525713341	11051

Table (9): Rheological Characteristics of Tested Specimens, Group III, (Test Temperature = 60°C, Q = 3.156 kg).

Mix. No.	Δf	η	P	E
25	9.2	275806956	0.531077488	10755
26	11.5	220645565	0.536461377	10466
27	14.6	173796164	0.542219989	10165
28	15.2	166935789	0.543191696	10155
29	9.4	269938723	0.531596378	10727
30	11.4	222581052	0.536250656	10477
31	14.6	173796164	0.542219989	10165
32	15.1	168041324	0.543032439	10123
33	9.1	278837802	0.530813797	10769
34	11.3	224550796	0.536038077	10488
35	14.5	174994758	0.542054164	10173
36	15.4	164767792	0.543507093	10099

Table (10): Difference in Modulus of Elasticity Values of Different Mixing Procedures (as Ratios of the TRP or TSP) for Coarser and Finer Gradations at Different Testing Temperatures.

Mixing Procedure / Testing temperature	TSP-TRP				SSP-TRP				SSP-TSP			
	C.G.		F.G.		C.G.		F.G.		C.G.		F.G.	
	Value, kg/cm²	Ratio, %*	Value, kg/cm²	Ratio, %*	Value, kg/cm²	Ratio, %*	Value, kg/cm²	Ratio, %*	Value, kg/cm²	Ratio, %#	Value, kg/cm²	Ratio, %#
20°C	137	1.07	156	1.3	185	1.44	189	1.54	48	0.34	33	0.27
40°C	28	0.25	27	0.25	20	0.18	14	0.13	58	0.51	41	0.37
60°C	28	0.26	8	0.08	14	0.13	-16	-0.16	14	0.13	-16	-0.16

C.G = Coarser gradation. F.G = Finer gradation.

* The ratio is based on the TRP values. # The ratio is based on the TSP values.

Table (11): Stiffness Modulus for the Investigated Asphalt Concrete Mixtures using the Van Der Poel Method.

Group I, Temp. 20°C		Group II, Temp.40°C		Group III, Temp.60°C	
Mix No.	S_{mix}, kg/cm²	Mix No.	S_{mix}, kg/cm²	Mix No.	S_{mix}, kg/cm²
1	70323	13	10549	25	1406
2	59775	14	7736	26	1055
3	45710	15	5977	27	598
4	42194	16	5625	28	562
5	77355	17	10759	29	1448
6	61181	18	8438	30	1082
7	46061	19	6033	31	632
8	42405	20	5675	32	590
9	78059	21	10829	33	1462
10	61814	22	8579	34	1104
11	46132	23	6040	35	635
12	42545	24	5689	36	592

Table (12): WTT Parameters.

Mix No.	TD_{35}-TD_{30} 0.005"	TR mm/hr.(x10⁻²)	CTR mm/hr.(x10⁻²)	D.S, pass/mm
25	0.6	30.48	50.94	4947
26	0.7	35.56	54.03	4664
27	0.75	38.1	55.74	4521
28	0.85	43.18	57.17	4408
29	0.55	27.94	50.43	4997
30	0.6	30.48	51.86	4859
31	0.7	35.56	55.42	4547
32	0.8	40.64	56.34	4473
33	0.5	25.4	48.91	5152
34	0.6	30.48	49.97	5043
35	0.75	38.1	54.54	4620
36	0.8	40.64	55.05	4577

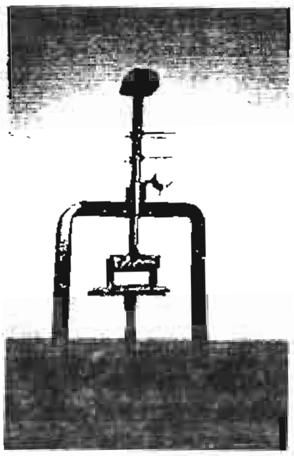

Figure (1): Radonesky Plastometer

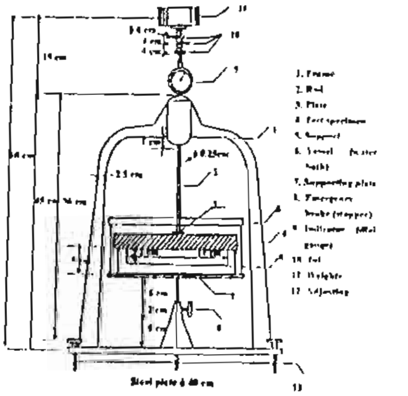

Figure (2): Vertical Section for Radonesky Plastometer device.

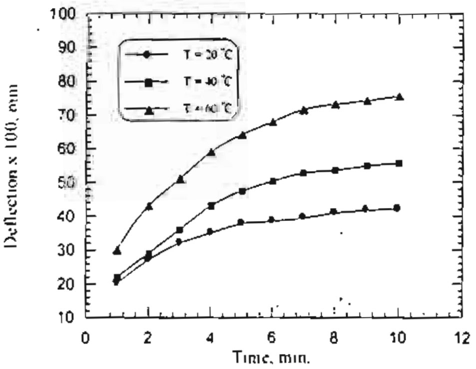

Figure (3): Relationship Between Time and Deflection for the Reference Mix at Different Testing Temperatures.

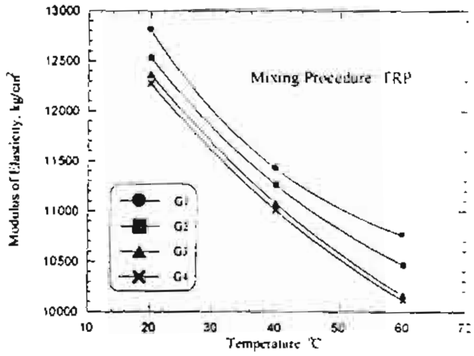

Figure (4): Relationship Between Modulus of Elasticity and Temperature for the Traditional Mixing Procedure (TRP).

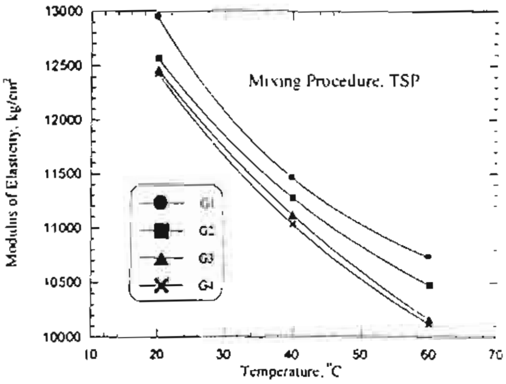

Figure (5): Relationship Between Modulus of Elasticity and Temperature for the Two-Stage Mixing Procedure (TSP).

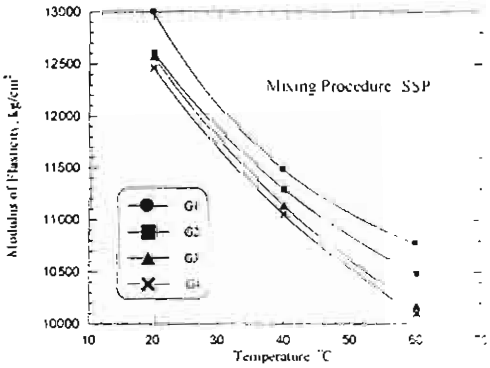

Figure (6): Relationship Between Modulus of Elasticity and Temperature for the Separate Successive Mixing Procedure (SSP).

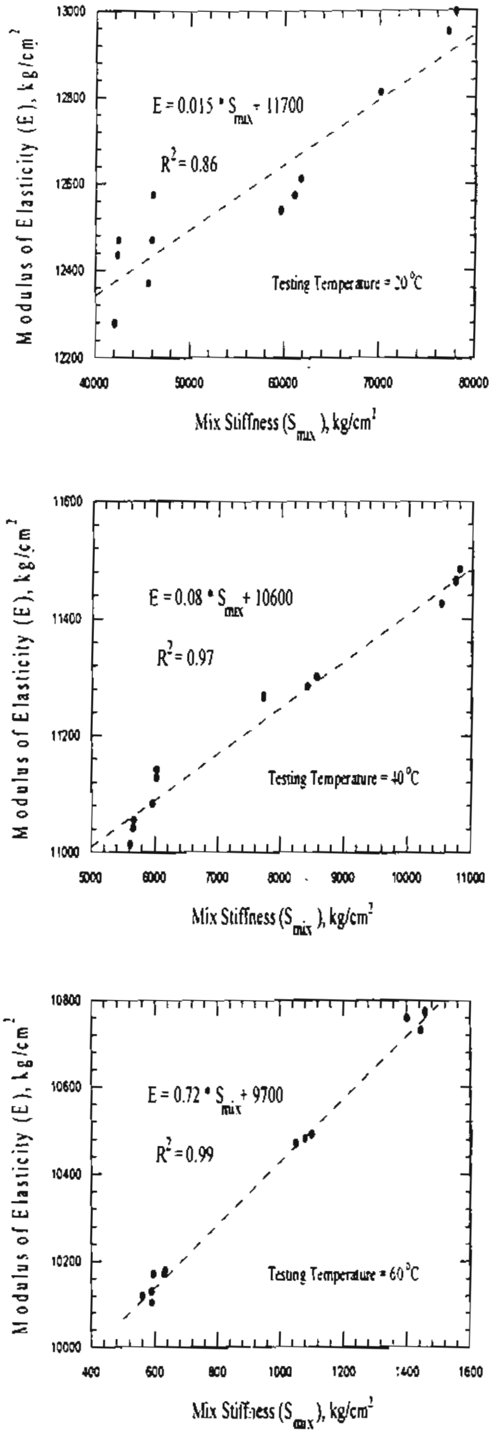

Figure (7): Relationship Between the Modulus of Elasticity and Mix Stiffness (Van-der Poel Method).

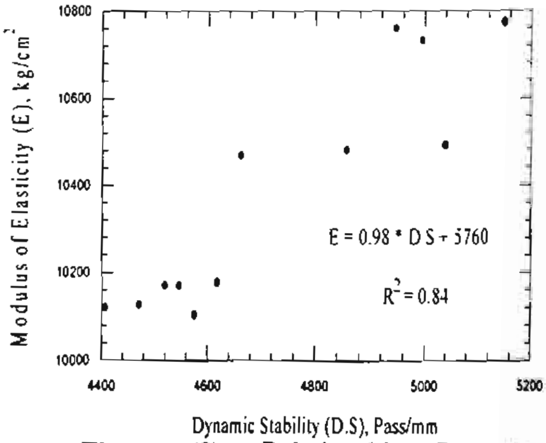

Figure (8): Relationship Between Modulus of Elasticity and Dynamic Stability.

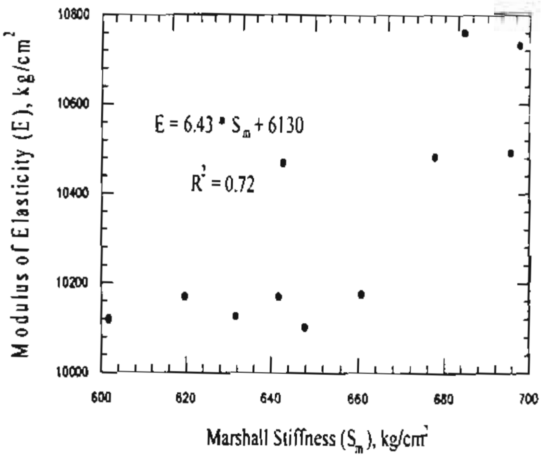

Figure (9): Relationship Between Modulus of Elasticity and Marshall Stiffness.