The Influence of Fines Content on the Mechanical Properties of Aggregate Subbase Course Material for Highway Construction using Repeated Load CBR Test

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Abstract:

The effect of fines content (material finer than 0.075 mm) on the mechanical properties of subbase course aggregate is studied in this paper. a laboratory tests were carried out using percentage of fines material 5%, 10% and 15% by weight adding to the original subbase aggregate class B according to Iraqi specification (SCRB) which the specification limit the range of fines between 5-15%. The repeated load CBR test was done to study the mechanical properties; accumulative permanent, elastic deformation and equivalent elastic modulus.

The RL CBR test was useful technique to assess the influence of fines material and stress level on the equivalent elastic modulus, and on the evolution of deformation. The equivalent modulus increase when adding 5% of fines material in case of plastic fines, but in case of non-plastic the increase continues until adding 10% fines material. Adding fines material also led to change in accumulative permanent deformation, where adding 5% fines material increase the permanent deformation by 36%, 5% for material with plastic fines and 20% for material with non-plastic fines for unsoaked samples. In case of soaked samples permanent deformation increase by 28% and 25% at adding fines material for material with plastic fines where decrease by 1% at adding 5% fines to original granular material with non-plastic fines. The theoretical modeling show that the deformation increase by increasing number of loads repetitions.

Keywords: Fines material, Subbase, Mechanical properties, Repeated load CBR, Granular material

1. Introduction

Flexible pavement consisting of a surface layer of hot mix asphalt, base and subbase layers of granular materials and subgrade. Many research efforts devoted to distinction the granular materials behaviour that is one of the main concerns of pavement engineers. The term "granular material" covers a variety of naturally occurring aggregate which in the context of this investigation refers particularly to those used in the subbase layers of a flexible pavement. In pavement engineering, CBR is generally used as a parameter to evaluate the suitability of a soil as pavement construction material. It is as well as used to estimate the resilient modulus and strength of subgrade, subbase, and base course materials .Usually the higher CBR value, the better the performance with regard to both the stiffness and strength (Luo, 2014)[1]. The cyclic load triaxial test is generally used to characterization the mechanical behavior of unbound granular materials such as the resilient modulus but this test are considered to be too expert and expensive to be carried out in road construction projects especially in developing countries so the distinction of unbound materials and soils is done by (RL CBR) test is which provides a more practical and simpler method (Araya et. al., 2011) [2]. Deformation in unbound granular materials under cycle loads is divided into an elastic part and permanent part which does not recover. The elastic strain represents the denominator in the resilient modulus and the non-recoverable strain results in permanent deformations by the time. Numerous factors are known to influence the deformation properties in unbound granular materials such grain size distribution, fines content (Uthus, 2007) [3].

Rutting is the more common damage as a result of permanent deformations in unbound granular materials (Araya, 2011) [4].The material passing No. 200 (75 µm) sieve have influence on the mechanical properties (resilient modulus and deformation) which done using RL CBR test instead of cyclic load triaxial test, due to the difficulty of using the triaxial device (Nawaf, 2015) [5].

2. The Aim of the Research

Investigate the effect of fines content (passing No. 200 (75 µm) sieve) on mechanical properties of granular material for subbase course using a (RL CBR) test depends on the CBR device which is available in most road engineering laboratories.

3. Materials

3.1 Granular Material for Subbase Course

The granular material for subbase was brought from three quarries Kasnzan (KA), Banslaoa (BA) and Daratoo (DA) in Erbil-Iraq. This type of subbase is commonly used as a layer in flexible pavement construction in Erbil and surrounding areas. According to the grading for each quarry and comparing the results with Iraqi specification (SCRB) the granular material are class B. The experimental works were done in Engineering College laboratories of Salahaddin University. The material have been first examined for their gradation (Figure 1) and their basic chemical and physical properties such as liquid and plastic limit, modified proctor density, CBR value in case of soaked and unsoaked. Liquid limit, plastic limit and plasticity index values are shown in Table (1). The modified proctor dry density vs. moisture content curves are shown in Figure (2). The dry density values with moisture content are (2165 kg/m³) at 7% M.C for material (KA), (2115 kg/m³) at 7.2% M.C for (BA) and (2230 kg/m³) at 6.2% M.C for (DA). Unsoaked and soaked CBR strength for three quarries are 67%, 69% and 72% for (KA), (BA) and (DA) in case of unsoaked CBR, 36%, 26% and 55% for (KA), (BA) and (DA) in case of soaked CBR.

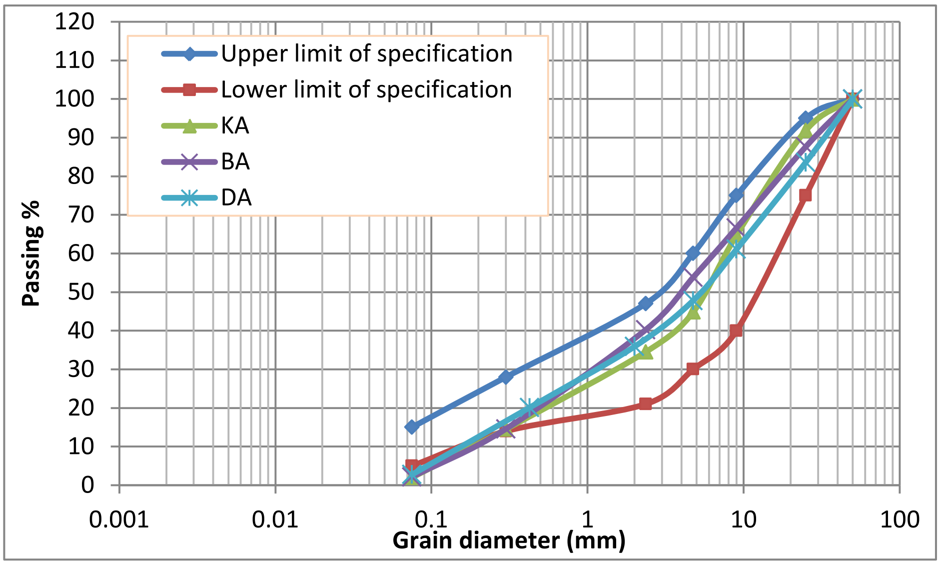


Figure 1: Grain size distribution of materials investigated

Table 1: Chemical and physical properties of investigated materials

No.	Properties	KA	BA	DA	Standards
1	SO3 Content %	0.31	0	0.38	Maximum 5%
2	Gypsum Content %	0.114	0.147	0.127	Maximum 10.75%
3	Liquid Limit (L.L %)	39	32	22	Maximum 25%
4	Plastic Limit (P.L %)	33	25	-	
5	Plasticity Index (PI%)	6	7	N.P	Maximum 6%

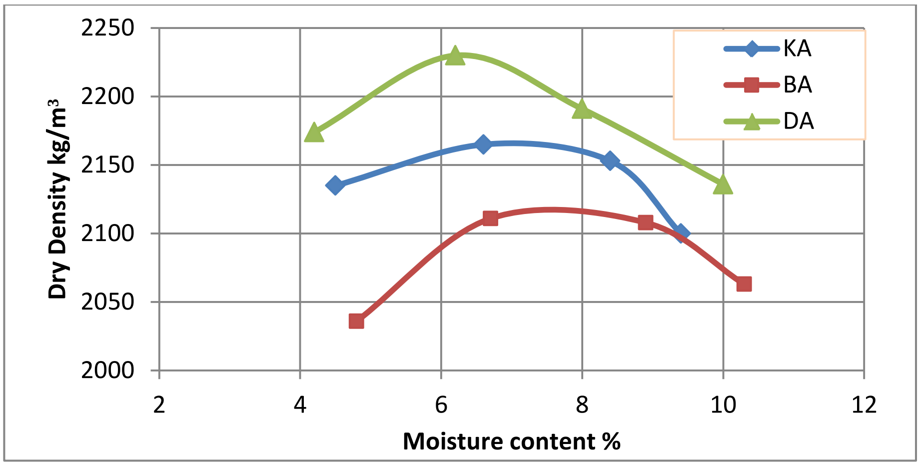


Figure 2: Dry density – moisture content relation of materials investigated

3.2 Fines Material

It is a material passing No. 200 (0.075mm) obtained from the same granular subbase material after dry sieving process. The hydrometer test was used to measure the gradation of fine material to determine percentage of silt and clay. Table (2) presents the percentage of silt and clay in each aggregate mix.

Table (2): Percentage of silt and clay

Aggregate mix	Silt %	Clay %
KA	65	35
BA	55	45
DA	73	27

4. Preparation of Samples

Granular materials for subbase layer were prepared by dividing it into four quantities: the first quantity is the original granular materials without any change in percentage of fines material which it 2%, 2.14% and 2.76% for (KA1), (BA1) and (DA1). The second quantity was prepared by adding 5% of fines material to the original granular material which represented (KA2), (BA2) and (DA2), the third quantity mix 10% fines with the original granular material which it (KA3), (BA3) and (DA3),and the fourth quantity mixed 15% fines material with the original granular material which represented (KA4), (BA4) and (DA4).

5. Test Set up and Method

5.1 Repeated Load CBR Test

The RL-CBR test was developed by Molenaar (2008) to take the advantage of the standard CBR equipment in repeated load CBR test. The purpose of the repeated load CBR test technique is to assess the resilient modulus (permanent and elastic deformation) of granular material by using the standard CBR testing equipment, Figure (3) with a repeated load cycles. The basis of the idea of the repeated load CBR test is comparable to the standard CBR test but the application of repeated load continue until reaching settled state. It is based on the concept by measuring the load and deformation during loading and unloading cycles, the resilient modulus can be estimated from the resilient (elastic) deformation and the respective load, the following procedure is used:

- The sample of CBR test was prepared according to the AASHTO T180 used in the preparation of standard CBR specimen. Using material passing 19 mm sieve.
- At first the sample was loaded, with the standard CBR test loading rate (1.27 mm/min), to reach deformation (2.54 mm). The load was recorded, after that the specimen is unloaded with similar loading rate (1.27 mm/min) to a minimum contact load of 0.3 MPa to keep the plunger in contact with the sample.
- The sample was re-loaded to the same load that was recorded on the same loading rate (1.27 mm/min), and unloading again more to the minimum of loading contact (0.3 MPa). The level of load in each cycle is keeping constant.
- Number of loading cycles were repeated for about (35 – 80) loading cycles at which the permanent deformation as a result of last five cycles loaded would be lower than 2% of the total permanent deformation at that point. The resilient and permanent deformation is calculated as shown in Figure (4).

Figure 3: CBR device

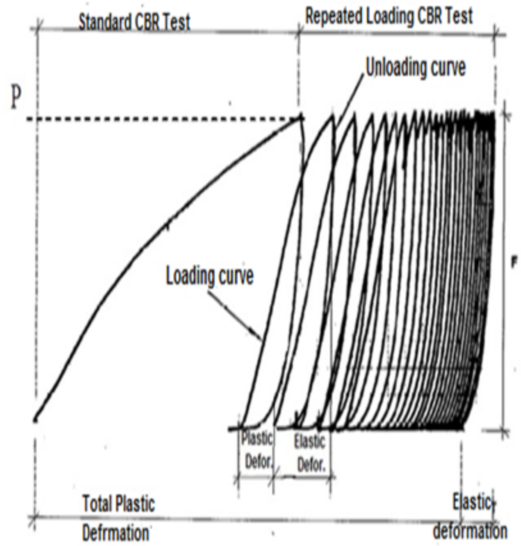


Figure 4: Repeated load CBR test principle (Molenaar, 2008)

The deformation in granular material under repeated load divided to two part; elastic deformation which is recoverable and permanent deformation. Elastic deformation occur a result to sliding, crushing and rearrangement of particles. The accumulative deformation must be considered when adding fines content because the accumulative permanent deformation of subbase layer have important effect on the rutting of pavement even the traffic volume low. The testing schedule is shown in Figure. (5). Under repeated load the accumulation of permanent deformation increase fast in the first few cycles and the incremental rate decrease as the number of repeated loads increase until becomes stable. Total 12 mixtures types were investigated for three quarries, 12 samples for unsoaked and 12 samples for soaked.

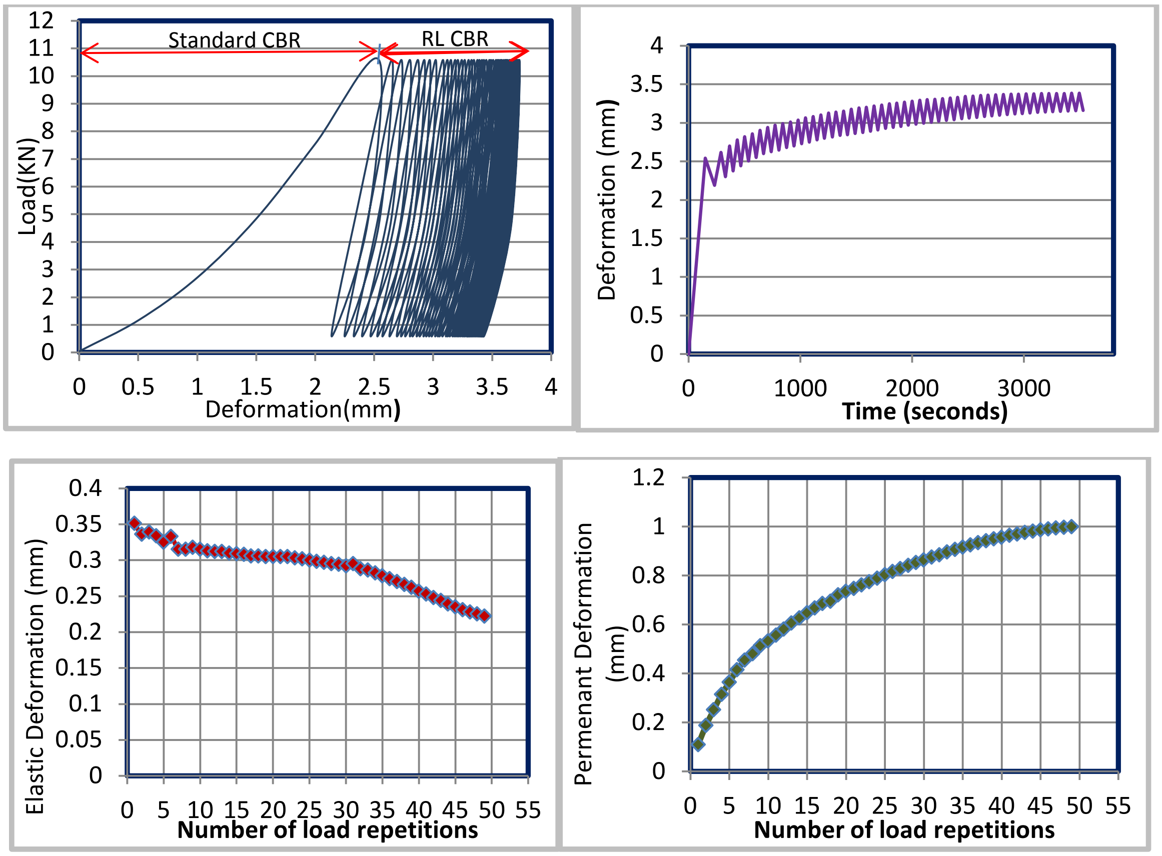


Figure 5: Repeated load CBR test

5.2 Calculation of the Equivalent Elastic Modulus (Eequ)

Plunger stress and the deformation are the main determinants which can be computed in the laboratory from the RL CBR. Modulus of elasticity (E) is calculated from the applied plunger stress (σp) and the elastic deformation of the specimen (u) in the final load application. Araya (2011) [4] developed an equation (1). It uses equivalent elastic modulus because it reflects the overall stiffness of the specimen as a bulk more than the resilient modulus of the material**.** The main cause for use of the resilient modulus or stiffness as a determinant for subgrade, subbase and base because it represents the basic material that can be used in mechanistic analysis for estimating different distress like rutting.

$$\text{Eequ} = \frac{1.513(1-\text{v}^{1.104})\Delta\sigma\text{p.r}}{\Delta u^{1.012}} \qquad (1)$$

Where:
Eequ = equivalent elastic modulus [MPa]
ν = Poisson's ratio [-]
Δσp=changing in stress between maximum and minimum limits in cycle loading [MPa]
r =plunger radius [mm]
Δu = changing in displacement between maximum and minimum limits in cycle loading [mm].
The value of Poisson's ratio ν depends on the type of material (granular material); a value of 0.4 is assumed (Maher, 2008) [6].

6. The Results and Discussion

The results were obtained from the test and discussion will be presented.

6.1 RL CBR Test Results

Figure (6) shows the relationship between elastic deformation and fines content for granular material (KA) highest elastic deformation is achieved at adding 5% fines content to the original material as a result to increase number of load repetitions and plunger stress and then decrease at adding 10% and 15% in case of unsoaked samples.
In case of soaked samples also elastic deformation increase at adding 5% fines material to the original material but decrease at adding 10% and 15% because of increase moisture content and the plastic fines be more sensitive to moisture and loss of elasticity.

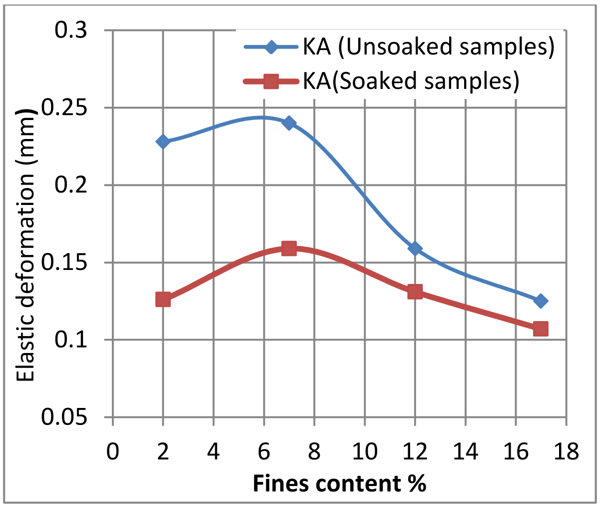


Figure (6) Fines content – Elastic deformation relationship for material (KA**)**

Figure (7) shows the relationship between elastic deformation and fines content for granular material (BA) adding 5% fines to the original granular material increase elastic deformation to but further adding decrease the elastic deformation due to decrease number of load repetitions in case of unsoaked samples. For soaked samples highest elastic deformation be at original granular material and adding fines content reduce the deformation because the clayey fines for this type of material which more sensitive to moisture content and loss the elasticity.

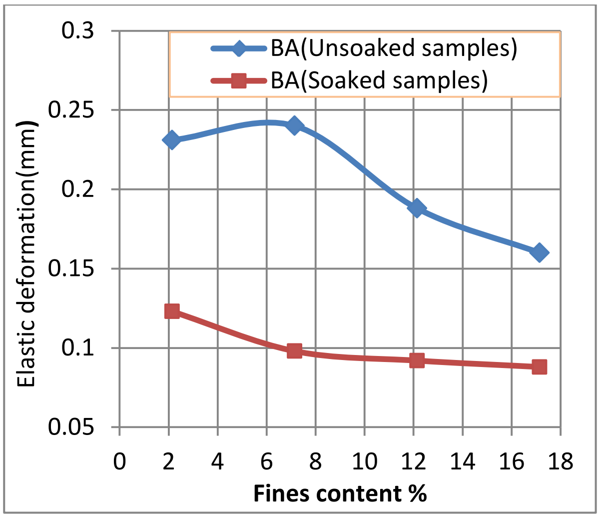


Figure (7) Fines content – Elastic deformation relationship for material (BA)

Figure (8) shows the relationship between elastic deformation and fines content. In case of unsoaked samples the elastic deformation increase at adding 5% fines to the original granular material due to increase number of load repetitions but further addition of fines decrease the elastic deformation. For soaked samples also increase the elastic deformation at adding 5% fines to the original granular material. Adding 10% and 15% decrease the deformation. As shown in the figure the difference between elastic deformation in case of unsoaked and soaked samples are little because it has silty fines (non-plastic) which are less affected by the moisture content.

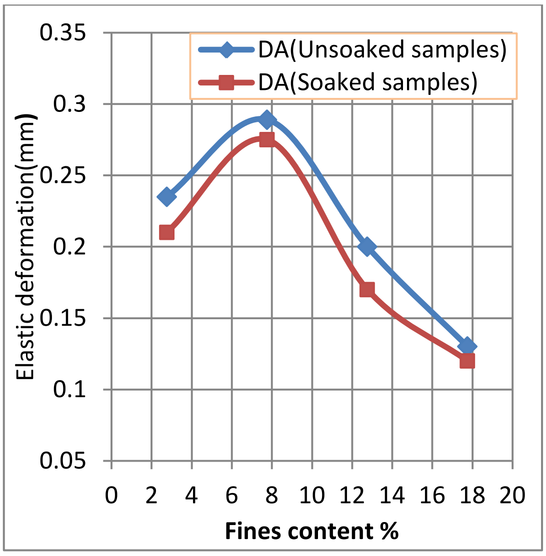


Figure 8: fines content – Elastic deformation relationship or material (DA)

Figure (9) shows the relation between accumulative deformation and fines content for unsoaked samples, highest permanent deformation is achieved at 8% for (KA) and (DA) but in case of (BA) highest permanent deformation is at 12% which has a highest value of PI because of having a high percentage of clay (45%) , and the clay have low resistance to deformation also grading has important effect on the permanent deformation where it has high percentage of fines grain (passing No.4 sieve), this assist to re-distributed the biggest grains. (DA) has a minimum deformation value among the other. Rutting occurs by large percentage at (BA).

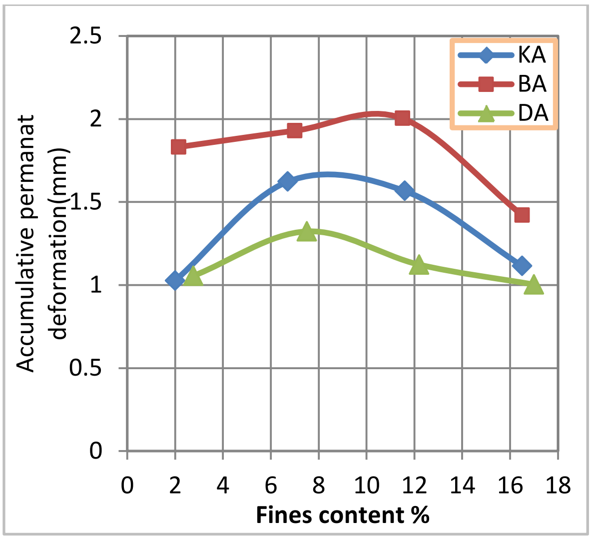


Figure (9) Fines content – accumulative permanent deformation relationship (unsoaked samples)

Figure (10) shows the relation between accumulative permanent deformation and fines content for soaked samples, highest permanent deformation is achieved at 10% for (KA) and (BA) but in case of (DA) highest permanent deformation is at 6% fines content and then decrease dramatically at 10% to be a minimum deformation value among the other. This refer to the manner of granular material under repeated load where (DA) has a maximum stress level before adding and at adding 5% of fines material which causes highest deformation among the other material but it decrease and be the less at adding 10 and 15% also the number of load repetitions affect the permanent deformation which increase by increasing number of load repetitions. The non-plastic fines are unstable in the presence of water and its deformation is anisotropic. Adding a small amount of fines content in which a small increase in moisture content can causes increase in permanent deformation**.**

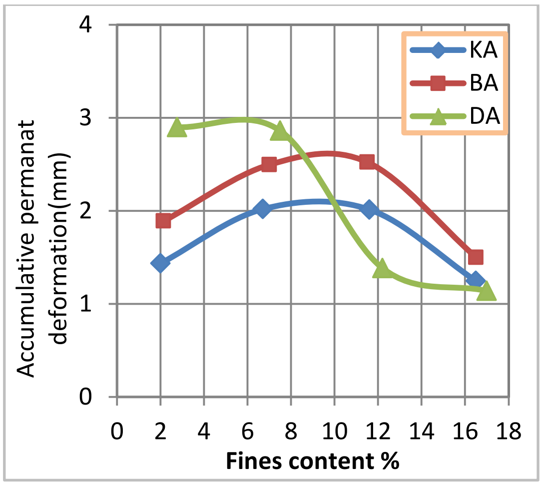


Figure (10) Fines content – accumulative permanent deformation relation (soaked samples)

Figure (11) shows the relation between fines content and Eequ, the equivalent modulus increase at 7% (adding 5%) and then reduce except DA (with non-plastic fines) which increase at adding 5 and 10% fines material and then decrease at adding 15% also DA have highest value of Eequ among three materials type**.**

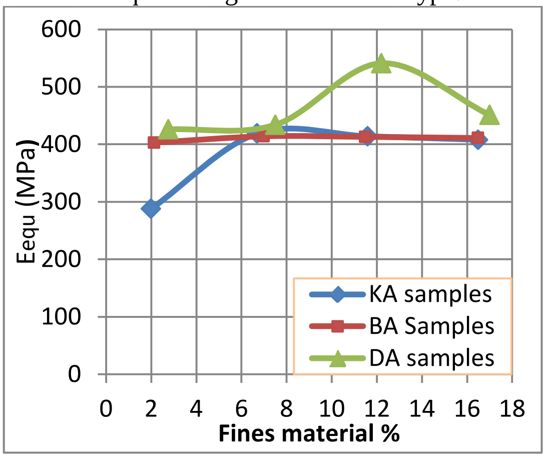


Figure (11) Eequ – Fines content relationship (unsoaked samples)

In case of soaked samples Figure (12), (BA) shows a different manner where Eequ have highest value before adding any fines content and decrease after adding fines . The Eequ modulus is mainly related to: the applied stress, number of load repetitions, gradation, moisture and density, so the increase in Eequ value at adding 5% refer to increase the number of load repetitions because the loss of moisture from the sample also increase with adding fines content but reduce after certain limits due to increase of moisture content this is explain the increase of Eequ modulus at adding 10% as raise in amount of moisture content with small percentage. (DA) has a highest value among the other materials because it has highest stress.

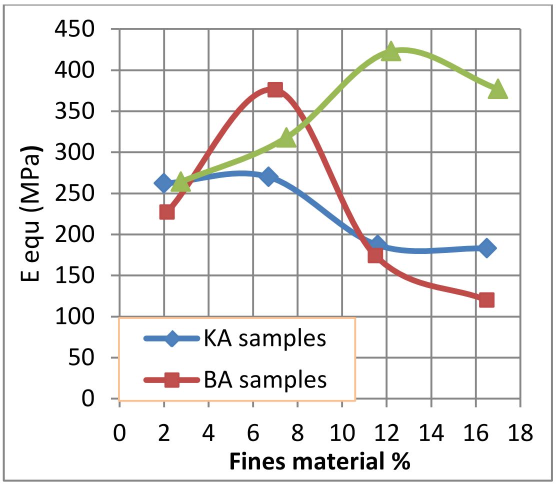


Figure 12: Eequ – Fines content relationship (soaked samples)

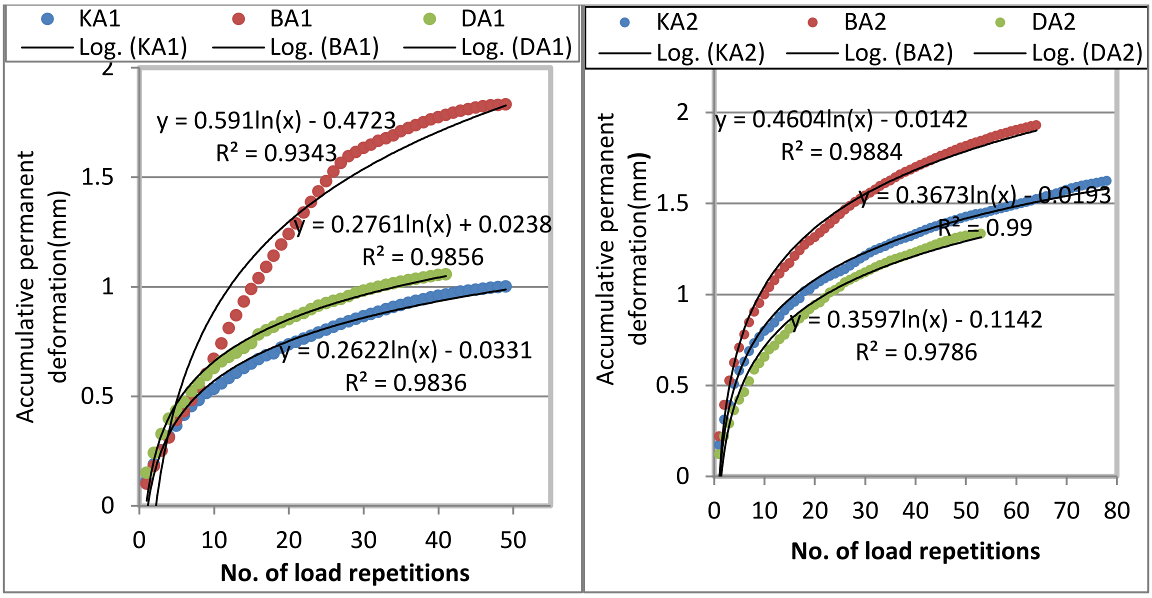
6.2 Correlation Accumulative Permanent Deformation with Number of Load Repetitions

Linear regression with excel is used to predicate correlation model for accumulative deformation with number of load repetitions. The equation (2) was developed.

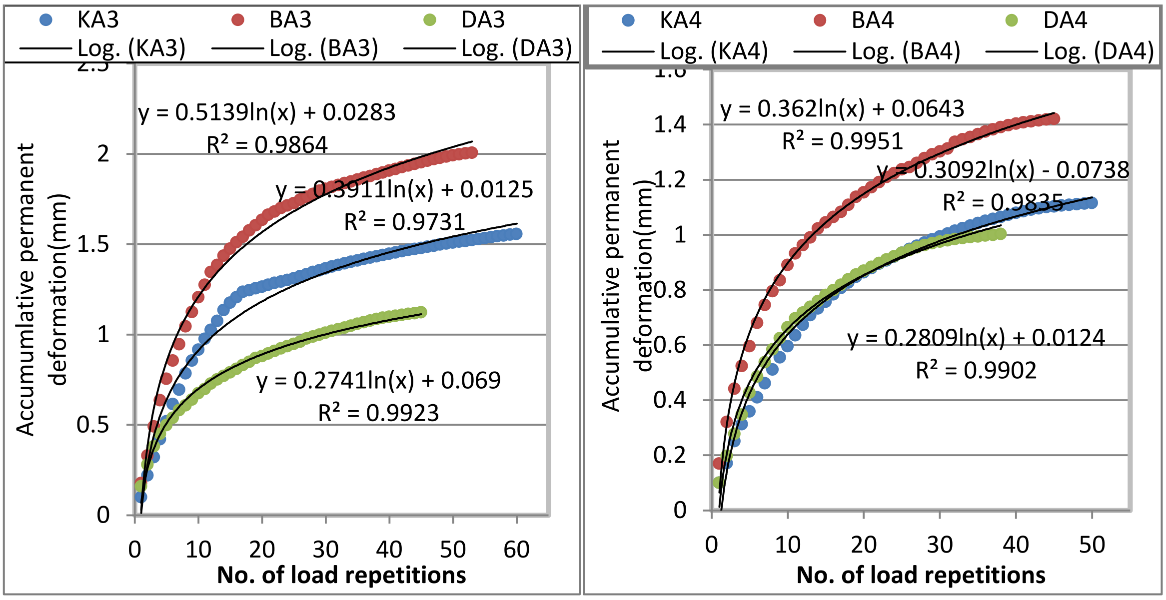
$$\text{Deformation} = b1 \ln(N) + b2 \qquad \dots (2)$$

Where:
N = Number of load repetitions
B1&b2= model parameters

Figure (13) present comparison between three material and fitting different models for natural aggregate without any change in percentage of fines material and at adding 5%, 10% and 15% fines material in case of unsoaked samples. The deformation is affected by number of load repetition (which simulates the load of moving vehicles), the model parameter b1show the degree of influence number of load repetitions at changing the percentage of fines content on the accumulative deformation where aggregate mix (BA) is the most affected by the number of load repetitions and aggregate mix (DA) is the less affected.
Figure (14) present comparison between three types of material in case of soaked samples. The model parameter b1 show that the aggregate mix (KA) before and at adding 5% fines material is the less affected by the number of load repetitions but at adding 10and 15% fines material the aggregate mix (DA) is the less affected.

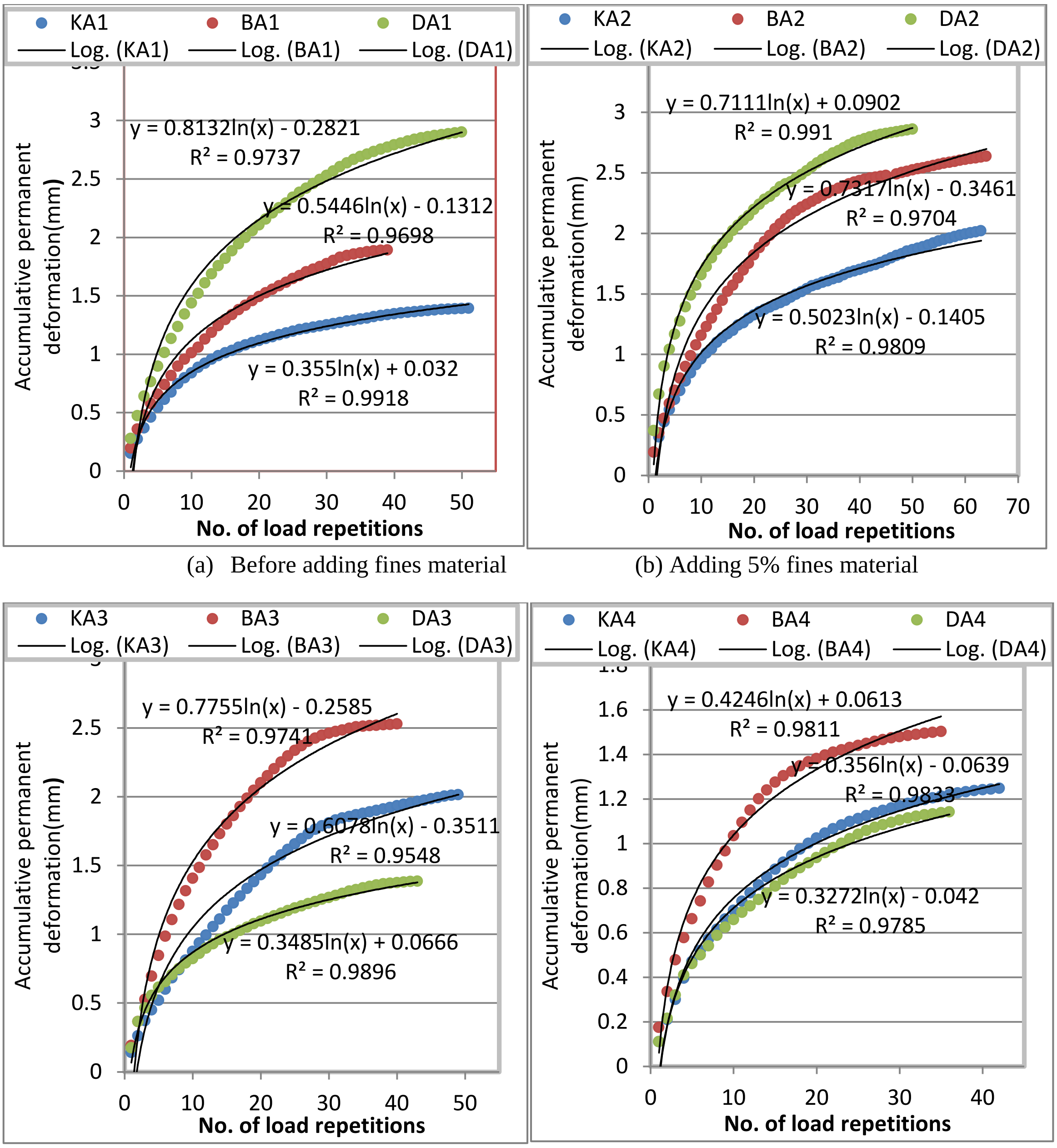


(a) Before adding fines material (b) Adding 5% fines material



(c) Adding 10% fines material (d) Adding 10% fines material

Figure 13: Correlation of accumulative deformation with number of load repetitions (unsoaked samples)



(a) Before adding fines material (b) Adding 5% fines material

(c) Adding 10% fines material (d) Adding 10% fines material

Figure 14: Correlation of accumulative deformation with number of load repetitions (soaked samples)

7. Conclusions

In this research, aggregate subbase course class B before and after 5, 10 and 15% fines were investigated. The fines were two types, medium plastic fines and non-plastic fines.

The conclusions reached are summarized as follows:

1. The procedure of the repeated load CBR is used to estimate the effect of fines content on the mechanical properties of the subbase aggregate. The results show that the repeated load CBR test can be used as useful technique for featuring the resilient deformation and accumulative permanent deformation when other testing method are not available. The RL-CBR test can reasonably reflect the accumulative deformation potential behaviour of tested material under traffic load.
2. For aggregate mix material (KA) and (DA) showed that elastic deformation increase at adding 5% fines material while (BA) aggregate mix show decrease at adding 5, 10 and 15% because of the nature of fines material which has a high percentage of clay (45%) and finer grading which loss elasticity by increasing stress and number of load repetitions this in case of soaked specimens. In case of unsoaked specimens the elastic deformation increases at adding 5% for three materials.

3. Permanent deformation increase by 36% for (KA) and 20% for (DA) aggregate mix at adding 5% fines to the original granular material and decrease by 3% and 15% at adding 10 where (BA) aggregate mix show increase at adding 10% by 9% because it has fines with high PI led to increase moisture content and has less dry density, this in case of unsoaked samples. In case of soaked samples aggregate mix (KA) show increase in permanent deformation by 28% at adding 5% fines where (BA) show that the accumulative permanent deformation increase at 10% by 25%, (DA) aggregate mix decrease by 1% at adding 5% fines and by 52% at adding 10% fines material.
4. Equivalent modulus influenced by fines content as a result of changes in the level of stress, elastic deformation and number of load repetitions due to change in the percentage of fines material. Equivalent modulus has highest value at adding 5% fines for (KA) and (BA) except (DA) which the increase continues to adding 10%. Another factor effect on the Eequ such as grading of granular material.
5. From the theoretical modeling parameter b1showed the accumulative deformation increase by increasing number of load repetitions where aggregate mix (BA) was the most affected by the number of load repetitions in unsoaked samples, but aggregate mix (DA) was less affected in case of soaked samples. Models having higher coefficient of determination R^2 (0.93 – 0.99).

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تأثير محتوى المواد الناعمة على الخصائص الميكانيكية لركام طبقة تحت الأساس في انشاء الطرق بإستخدام فحص التحمل الكاليفورني للأحمال المتكررة

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الخلاصة

يقدم هذا البحث دراسة لتأثير المحتوى الناعم (المواد الأنعم من 0.075 ملم) على الخصائص الميكانيكية لركام طبقة تحت الأساس . الفحوصات المختبرية نُفذت بأستخدام نسب من المواد الناعمة 5%, 10% و 15% من الوزن مضافة الى ركام تحت الأساس نوع B حسب المواصفة العراقية الذي فيه حدود المواصفة للمواد الناعمة بين (5- 15%). تم تنفيذ فحص نسبة التحمل الكاليفورني للأحمال المتكررة لدراسة الخصائص الميكانيكية; التشوه الدائم التراكمي, التشوه المرن ومعامل المرونة المكافيء. فحص نسبة التحمل الكاليفورني للأحمال المتكررة تقنية مفيدة لتقييم تأثير المواد الناعمة ومستوى الاجهاد على معامل المرونة المكافيء وتطور التشوه. معامل المرونة المكافيء يكون في اعلى قيمة عند اضافة 5% من المواد الناعمة في حالة المواد الناعمة اللدنة لكن في حالة المواد عديمة اللدونة الزيادة تستمر حتى عند اضافة 10%من المواد الناعمة. اضافة المواد الناعمة كذلك يؤدي الى تغيير في التشوه الدائم التراكمي حيث اضافة 5% من المواد الناعمة يزيد التشوه الدائم بنسبة 36% و 5% بالنسبة للمواد ذات محتوى ناعم لدن وبنسبة 20% للمواد الحاوية على مواد ناعمة عديمة اللدونة للنماذج غير المغمورة. في حالة النماذج المغمورة التشوه يزيد بنسبة 28% و25% عند اضافة المواد الناعمة اللدنة بينما تقل بنسبة 1% عند اضافة 5% مواد ناعمة الى المواد الاصلية عديمة اللدونة . النمذجة النظرية اظهرت ان التشوه يزداد بإزدياد عدد مرات الحمل.

الكلمات الرئيسية: المواد الناعمة، تحت الأساس، الخصائص الميكانيكية، نسبة التحمل الكاليفورني للأحمال المتكررة، المواد الحبيبية