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Flexural and Cracking Behaviour of Roller Compacted Asphalt Concrete

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Abstract

This work is intended to evaluate the flexural and cracking behavior of both Dense and Gap graded Asphalt concrete. Slab samples of 30×30×7cm size have been constructed in the laboratory using the TRRL roller wheel compactor. Various Asphalt percentages were adopted.

Beams were sawed from the slabs at two different positions (parallel and perpendicular to rolling direction). Beams were tested for flexural strength at 8°C and the load-deformation relationships were obtained.

The flexural modulus, the stiffness and E- Modulus were determined. The deflection and cracking of beams were observed and the various modes of displacement were studied. It was concluded that rolling direction has a significant effect on fracture strength for both Dense and Gap graded Asphalt Concrete; The predicted displacement of beams with Gap gradation were higher especially at high Asphalt content when compared to Dense mixes while the variation of measured displacement between Dense and Gap mixes is not significant.

E- Modulus of dense mixes was higher at various Asphalt percentages. On the other hand, the variation of both flexural and stiffness modulus at optimum Asphalt content was not significant for all of the mixes studied.

الخلاصـــة

*يهدف هذا البحث إلى تقييم سلوكية الخرسانة الإسفلتية بنوعيها العالية الكثافة أو ذات النواقص في التدرج أثناء الكسر والتشقق حيث تم تحضير نماذج سقفية في المختبر من الخرسانة الإسفلتية بقياس (٣٠*٣٠*٧) سم باستخدام حادلة مختبر بحوث المواصلات والطرق البريطاني ذات الإطار المعدني وباستخدام نسب مئوية مختلفة من الإسفلت.*

تم قطع أعتاب من هذه النماذج السقفية وباتجاهين (موازي أو عمودي على اتجاه الحدل) و تم فحص هذه الأعتاب تحت درجة حرارة ٨ °م لإيجاد معاير الكسر وتم الحصول على علاقات الإجهاد بالانفعال لها.

تم الحصول على كل من معاير الكسر؛ معاير الصلادة؛ ومعاير المرونة حيث تمت ملاحظة كل من الانفعال والتشقق في هذه الأعتاب ودرست الأنواع المختلفة لمراحل الانفعال كما تم الاستنتاج بان اتجاه الحدل كان ذو اثر فاعل على مقاومة الكسر للخرسانة الإسفلتية بنوعيها العالية الكثافة أو ذات النواقص في التدرج إن الانفعال المتوقع للأعتاب ذات النواقص في التدرج كان كبيرا عند مقارنته مع مثيله في النماذج عالية الكثافة عندما تم استخدام نسب إسفلت عالية، بينما كان الفرق في الانفعال المحسوب بين النماذج للخرسانة الإسفلتية بنوعيها العالية الكثافة أو ذات النواقص في التدرج غير ملحوظ.

كان معامل المرونة للنماذج عالية الكثافة أعلى ولجميع نسب الإسفلت المئوية المستخدمة بينما كان الفرق في كل من معاملي الكسر والصلادة عند نسبة الإسفلت المثالية غير مؤثر ولجميع الأعتاب التي تمت دراستها.

1. Introduction

The main types of structural distress of Asphalt Concrete pavement are cracking and permanent deformation. At low pavement temperature, the heavy traffic loading makes the pavement more susceptible to cracking since the Asphalt Cement can be so hard and the vehicle loading cause brittle fracture of the binder film. The resistance of the mix to such type of cracking is in its flexural properties.

2. Previous Experience

A majority of research into the cracking of Asphalt Concrete stated that crack is divided into an initiation element which is strain dependent and a propagation element which is considered to be stress dependent [1,2, 3].

Fracture cracking may be analyzed using two approaches, the fracture mechanics approach which treats a crack as a discrete discontinuity in the material at which the damage occurs, and then the crack growth depends on stress intensity, while the second approach was the damage mechanics which recognizes that damage is spread over the whole body of the material and there is stiffness loss from the material before any crack becomes visible [4,5].

The effect of mix composition variables on low temperature stress-strain behavior and fracture strength of Asphalt concrete have been studied by [6], he concluded that the types of aggregate had an appreciable effect on the modulus and fracture strength, while Asphalt content variation of 0.5% above and below optimum had little effect on tension and fracture modulus.

Four point bending beam test was conducted by [5], they concluded that the test is able to describe the failure process of Asphalt Concrete under tension caused by flexure.

At low temperature, Asphalt mixes exhibit elastic behavior, and the elastic theory could be applied as stated by [7], they concluded that for such elastic material, the modulus of rupture and the flexural stiffness would be more reliable parameters for mix evaluation purpose. The modulus is defined as the ratio of stress to strain; This is defined as stiffness modulus which is also called flexural stiffness at beam test.

Flexure and cracking phenomena of Asphalt Concrete have been studied by [8] for dense graded mixes, failure of beams was divided into three stages, fatigue damage, relaxation and chemical healing. He concluded that the displacement of beams is due to the combined effect of bending, shear and cracking.

3. Material Properties and Testing

3.1 Coarse and Fine Aggregates

Crushed coarse and fine aggregates from river origin were obtained from Mosul Asphalt Plant, and were divided into different sizes by sieving, oven dried, and stored in plastic containers; their properties were illustrated in **Table (1)**.

Table (1) Physical Properties of Aggregates

Type	Bulk specific gravity	Los-Angles abrasion%
Coarse aggregate	2.650	17
Fine aggregate	2.600	16

3.2 Gradation

Dense gradation as per (SORB-1983) for binder course and Gap gradation as per (B.S.594-1961) were used throughout the investigation. The grain size distribution is illustrated in **Fig.(1)**.

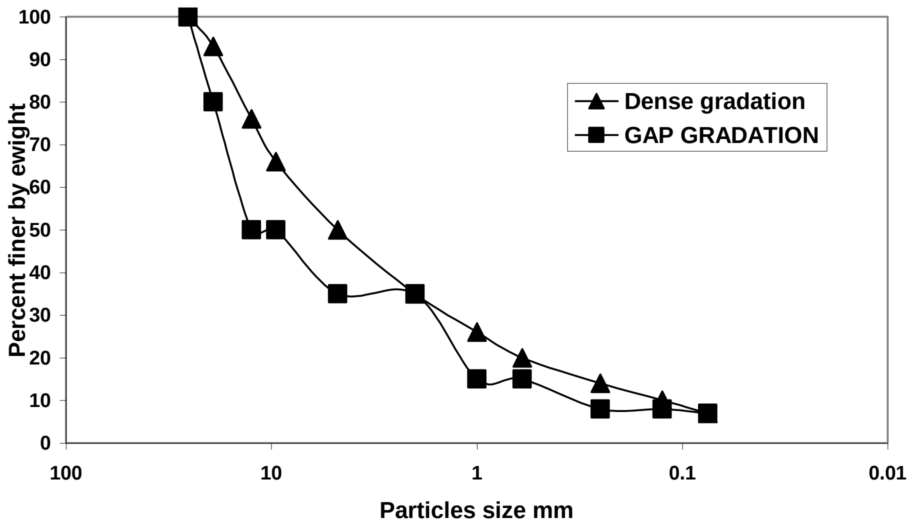

Figure (1) Grain Size Distribution of the Design Mixes

3.3 Filler

Ordinary Portland Cement obtained from Badosh Cement factory was introduced as the filler material in Asphalt Concrete mixes. **Table (2)** shows its properties.

Table (2) Gradation of Cement

Sieve size	% Finer by weight
No.120	100
No.200	92

3.4 Asphalt Cement

Asphalt Cement of grade (40-50) was obtained from Gayara oil refinery stock **Table (3)** shows its various properties.

Table (3) Properties of Asphalt Cement

Test	Sample	Specification SORB
Penetration at 25°C, 100 gm, 5 sec, (0.1 mm)	42	40-50
Specific gravity	1.040	
Ductility - 25 ° C, 5 cm/min	+ 100	+ 100 min.
Loss on heating 5hr, 163 ° C (%)	0.3	0.75 max.
Softening point ° C	54	51-62

4. Testing Program

4.1 Roller Wheel Slab Samples Construction

The required amount of aggregate of different sizes to prepare a slab specimen of (30×30×7) cm size was weighted, heated to 160˚C and combined. Asphalt Cement was also heated to 150˚C, and then the predetermined amount of Asphalt was added to the aggregate into the preheated mixing bowel. Mechanical mixing was conducted for two minutes, then the mix was poured into the preheated slab mould of the TRRL roller wheel tracking machine, leveled with a spatula, then it was subjected to 10 passes of the steel roller wheel for each of the three stages of compaction using different compaction effort for each stage by changing the applied normal load. A primary compaction by roller was applied using 10 passes of the machine shoe with a normal load of 10kg/cm width, followed by 10 passes using a normal load of 20kg/cm width. Such compaction may represent the primary and heavy compaction applied by steel and pneumatic tire rollers in the field. The final compaction was demonstrated by the application of 10 passes of the roller using 45kg/cm width normal load representing the finishing compaction by steel rollers in the field [9,10]. Samples were kept overnight in the mould for cooling, then withdrawn from the mould for further testing. A total of 6 slabs were compacted as above using both dense and gap gradations with three Asphalt percentages of (4, 5, 6) %.

4.2 Roller Samples Testing

Sawed beams of 6×7×30 cm cut from a position parallel to rolling direction, and 6×7×24 cm beams cut from a position perpendicular to rolling direction were obtained from the slab samples as per (ASTM C42-64-1982) [11] for flexural properties determination. A total of three beams were obtained from each slab samples.

All of the beam samples were subjected to bulk specific gravity determination before testing for flexural stress.

Beam samples cut from a position parallel to rolling direction were subjected to flexural testing using the four point loading geometry according to(ASTM C78-64-1982) [11], while beam samples cut from a position perpendicular to rolling direction were tested using three point loading geometry as per (ASTM C293-64-1982) [11].

Normal load was applied only, no shear stress was allowed by using the roller supports. A pure bending at mid part of the beam was achieved. Beams and the roller supports were stored in a refrigerator at 8˚C for four hours prior to testing.

5. Analysis and Discussion of Test Results

5.1 Fracture Strength of Asphalt Concrete

The potential of Asphalt Concrete to fracture at low temperature was evaluated by determining the flexural Modulus, stiffness and E-Modulus which are considered as a measure of the energy required to initiate crack growth. Most rational analysis of pavement behavior has shown that flexure stress is the critical factor affecting initiation and early propagation of load related cracks.

As demonstrated in **Fig.(2)** and **(3)**, both Dense and Gap graded Asphalt Concrete mixes shows high modulus of rupture at 5% Asphalt content which is supposed to be the optimum binder content.

Dense gradation shows higher modulus of rupture for beams cut from a position parallel to rolling direction than that of beams cut from a position perpendicular to rolling direction, the variation is within 73% at 5% binder content. On the other hand, Gap gradation shows higher modulus of rupture for beams cut from a position perpendicular to rolling direction than that of beams cut from a position parallel to rolling direction, the variation is within 183% at 5% binder content.

The variation of modulus of rupture at higher or lower Asphalt content was not significant for both Dense and Gap gradation and for both beams cut positions.

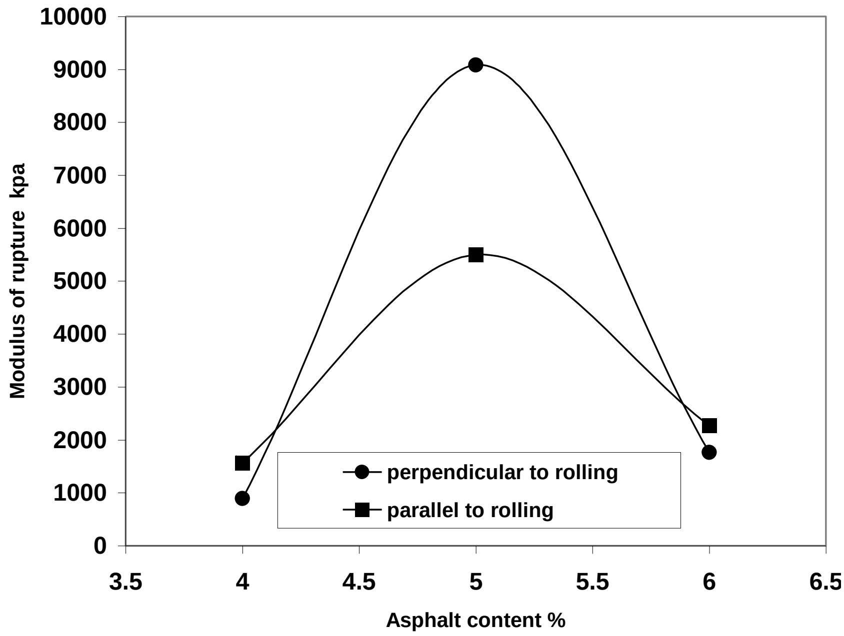

Figure (2) Modulus of Rupture of Dense Graded Asphalt Concrete

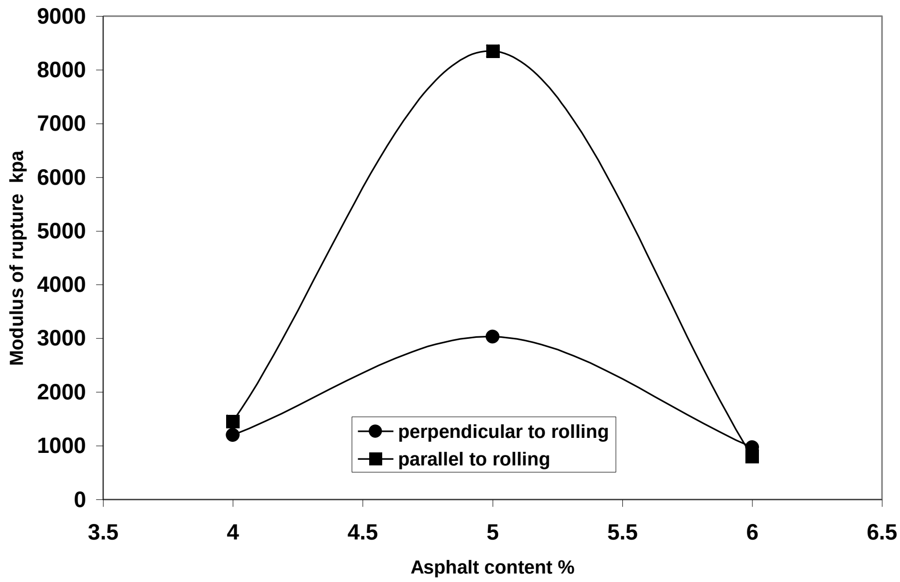

Figure (3) Modulus of Rupture of Gap Graded Asphalt Concrete

Figure (4) shows that dense gradation has higher E-Modulus when compared to Gap gradation, dense mixes have high E-Modulus at lower binder content, while the variation of E-Modulus at different Asphalt percentages for Gap mixes is not significant.

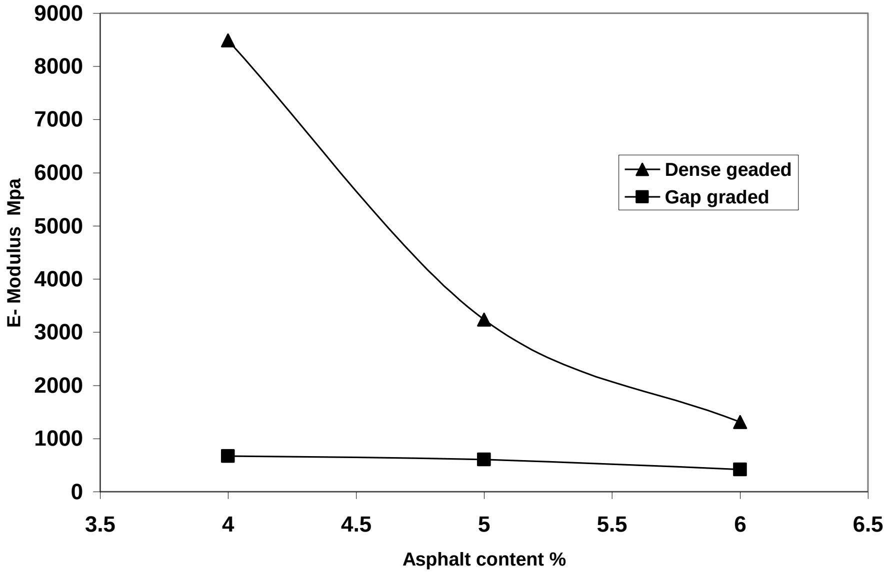

Figure (4) Modulus of Asphalt Concrete

Figure (5) illustrates that the stiffness modulus is low at 5%binder for both gradation types; such finding is supported by high modulus of rupture as explained above.

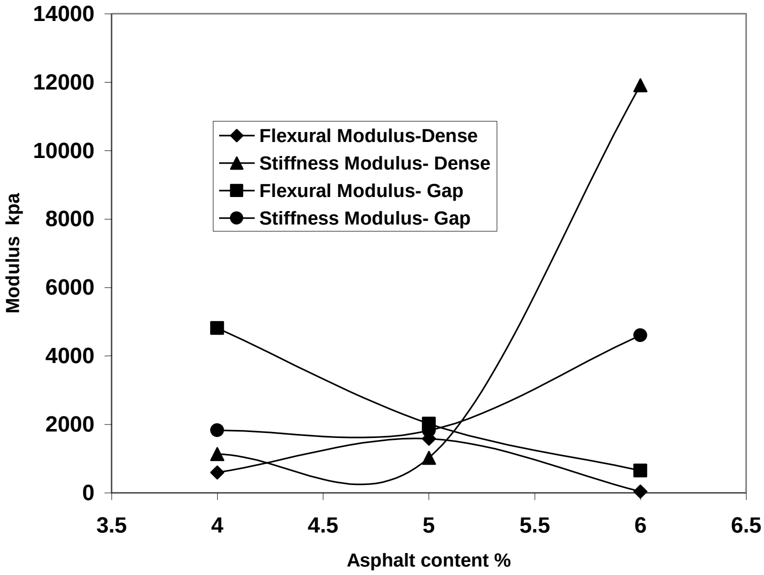

Figure (5) Modulus of Asphalt Concrete

It is desirable to have a high modulus of rupture to ensure adequate tensile strength and at the same time have a low stiffness modulus to avoid being excessively brittle. On the other hand, both gradation types have almost the same flexural modulus at 5% binder content. It was believed that when a load is applied to the pavement beam, it causes bending that produces flexure stress which is critical since it will approach the ultimate tensile strength of

Asphalt Concrete. Dense graded mixes shows the highest flexural modulus at 5% binder content, while Gap graded mixes shows the same at 4% binder content.

5.2 Displacement and Cracking Properties of Asphalt Concrete

Figures (6) and **(7)** shows various types of displacement for Dense and Gap graded mix, the total vertical displacement was large enough to cause major cracks in the mixes.

Crack initiation is visible at low binder content, but the visibility of the crack in Dense graded beam at 4% Asphalt content was much more pronounced than that in Gap graded beam. Cracking has a minor effect especially at high Asphalt percentages and bending and shear stresses are responsible for total displacement at Dense graded beams.

For Gap graded mixes, it was felt that bending and shear stresses are responsible for major displacement of the beams; this responsibility is increasing as Asphalt content increases.

The calculated total displacement is higher than the measured displacement for both gradation types and for various Asphalt percentages, such variation increases at high Asphalt content.

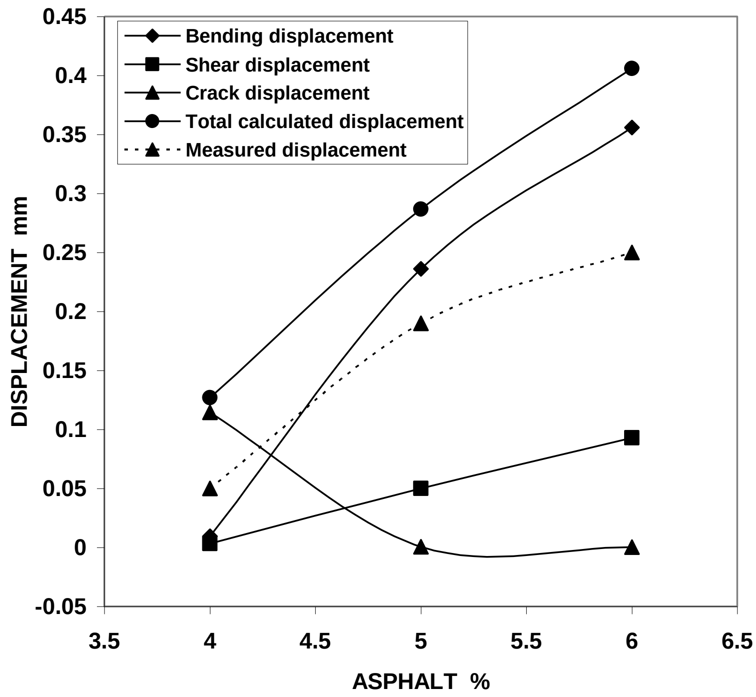

Figure (6) Displacement of Dense Graded Asphalt Concrete

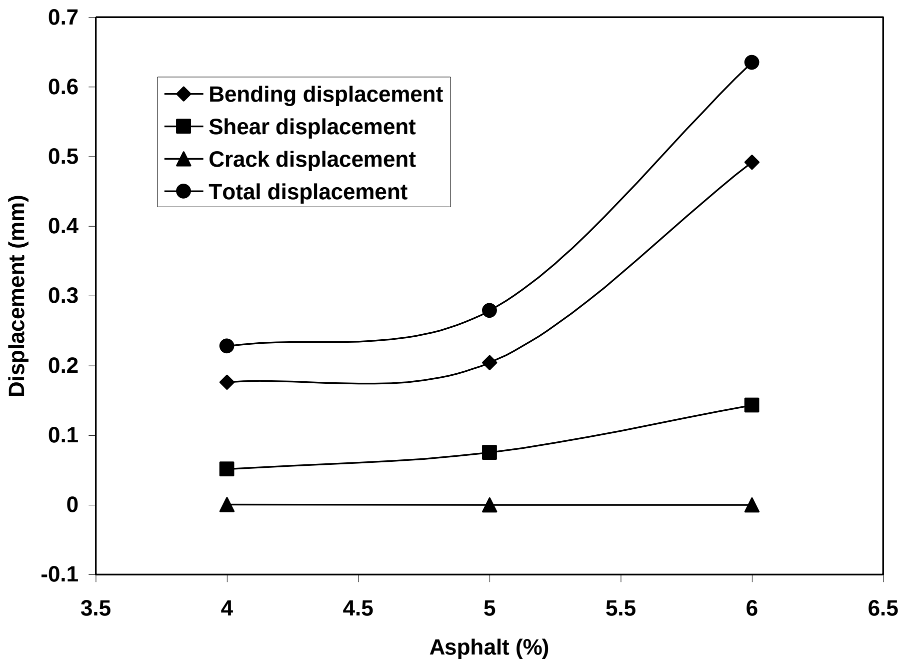

Figure (7) Displacement of Gap Graded Asphalt Concrete

Figure (8) shows typical load-strain relationship at 5% binder content for both Dense and Gap mixes; it clearly indicates that dense mix is stiffer and more brittle than gap mix. Gap graded mix shows elastic failure while Dense graded mix shows cracking and brittle failure. Such finding correlates well with [4,12,13] findings.

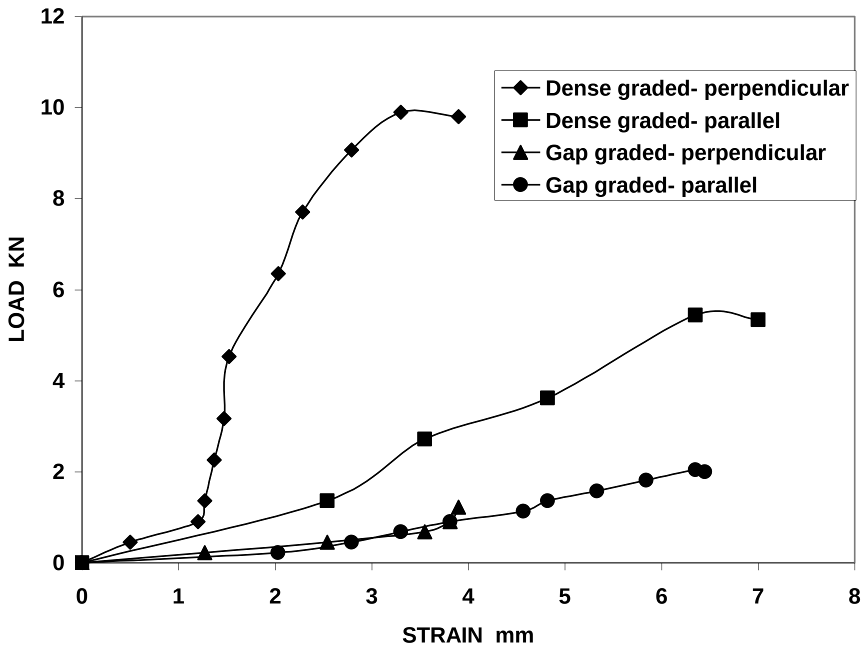

Figure (8) Typical Load-Strain Relationship at 5% Asphalt Concrete

6. Conclusion

Based on the limited testing program, the following conclusions may be drawn:

1. Dense graded mixes is indicating an optimum performance at 5% Asphalt content (i.e. low stiffness modulus, high flexural and E-Modulus, and high modulus of rupture), however it is stiffer and more brittle than Gap graded mixes at 8˚C testing temperature.

2. The rolling direction of the tested beams has a significant effect on fracture strength for both Dense and Gap graded mixes at optimum Asphalt content of 5%, however, the effect is minor at higher or lower Asphalt percentage.

3. The total displacement of Gap graded mixes is higher than that of Dense graded mixes.

4. Bending and shear stresses are responsible of total displacement for Gap graded beams, while cracking has minor effect on total displacement.

5. Cracking has the major responsibility for displacement of Dense graded beams at 4% binder content, at higher Asphalt percentage, bending and shear stress are responsible for the total displacement.

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