Al-Qadisiya Journal For Engineering Sciences, Vol. 5, No. 4, 424-438, Year 2012

LABORATORY INVESTIGATION INTO THE IMPACT OF POLYPROPYLENE FIBER CONTENT ON TEMPERATURE SUSCEPTIBILITY OF DENSE GRADED MIXTURES

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ABSTRACT
The mechanical properties of asphalt mixtures used in highways construction depend to large extent on the type and quantity of the used asphalt. With time any asphalt pavement can exhibit various distresses that will eventually lead to the pavement failure.
Various types of additives and modifiers have been used in asphalt to mitigate the distresses**.** Fiber is one of the additives used for this purpose. The principal function of the fiber is to provide additional tensile strength in the resulting composite. This could increase the amount of strain absorbed during the fatigue and fracture process of the mixture.
In local asphalt pavement, the severity of permanent deformation and thermal cracking has been increased due to the increase in track axle loads, tire pressure, and the difference in pavement temperature, therefore, the modified dense graded mixtures with polypropylene fibers suggested for use in highway wearing courses to provide adequate resistance to permanent deformation and to provide additional tensile strength in the resulting composite.
The effects of variation in polypropylene fiber content, asphalt cement content, aggregate gradation and testing temperature are evaluated through the results of Marshall Methodology, indirect tensile strength, indirect creep test, and ultrasonic testing.
The results obtained from this study showed that the PPF improved the mixture's performance in several unique ways against the anticipated major pavement distresses.
The addition of (0.3%) polypropylene fiber by weight of total mix with type (A) aggregate grading will help in produce more flexible mixtures that are also more resistant to permanent deformation and thermal cracking.
The relationship between the dependent and independent variables was examined by descriptive statistical analysis. The SPSS statistical package was used to perform this analysis.

الموجز
أن الخصائص الميكانيكية للخلطات الاسفلتية المستخدمة في أنشاء الطرق تعتمد بدرجة كبيرة على نوع وكمية الأسفلت المستخدم. مع الزمن فأن طبقات التبليط تواجه العديد من التشوهات التي قد تؤدي الى الفشل. ولغرض التقليل من تأثير التشوهات فقد تم أستخدام العديد من المضافات والمحسنات.
يعتبر الفايبر احد المضافات المستخدمة لهذا الغرض. اذ ان الوظيفة الاساسية له هي زيادة مقاومة الشد للخليط وتقليل الانفعالات الناشئة المسببة للتكسر والكلل.

ان مشكلة التشوهات الدائمة والتشققات بسبب الحرارة في سطوح خرسانة التبليط المحلية تتزايد بصورة مستمرة بسبب الزيادة في الاحمال المرورية المسلطة والفرق في درجات حرارة التبليط لذا فان الخلطات الاسفلتية المحسنة بأستخدام البولي بروبلين فايبر المقترح أستخدامها في طبقات التبليط السطحية لتوفير المقاومة الكافية للتشوهات الدائمة ولزيادة مقاومة الشد للخليط وبالتالي تقليل التشقق الناتج بسبب الحرارة.

أن تأثير التغير في نسبة البولي بروبلين فايبر والمحتوى الأسفلتي وتدرج الركام ودرجة الحرارة قد تم بيان تأثيرها من خلال المؤشرات التالية : خصائص مارشال وفحص الشد غير المباشر وفحص الزحف ومعامل المرونة. نسبة إلى نتائج الاختبارات اعلاه في هذا البحث فقد تبيّن أن أضافة (0.3%) بولي بروبلين من وزن الخليط الكلي مع تدرج الركام نوع (A) يساهم في تحسين المقاومة للتشوهات الدائمية والتشققات بسبب الحرارة، وقد تم تقديم الاستنتاجات الرئيسية المتعلقة بتأثير أستخدام البولي بروبلين فايبر على أداء الخليط بالإضافة إلى دور كل من المتغيرات الأخرى المثبتة أعلاه في هذا التقييم. تم إعداد نماذج إحصائية للمساعدة في التنبؤ عن تأثير بعض المتغيرات المختلفة على قيم الأنفعال.

KEYWORDS: Polypropylene Fiber, Dense Graded, Additives, Indirect Tensile, Temperature.

INTRODUCTION

Asphalt cement modifiers have been used in pavement technology to enhance pavement performance and reduce different types of pavement distress, of which, rutting, low temperature cracking, load associated fatigue cracking, stripping, and hardening are the most common. Fiber is one of the additives used for this purpose (**Thomas and Haiming, 1999**).

Using fibers to improve the behavior of materials is not a new concept. Fibers are widely used as reinforcing agent in concrete, however, the modern ways of fiber reinforcement started in the early 1950s (**Saeed and Ali, 2000**).

The principal function of the fiber is to provide additional tensile strength in the resulting composite. This could increase the amount of strain absorbed during the fatigue and fracture process of the mixture Fibers are sometimes added to stabilize the binder during mixing and placement. An additional benefit of using fibers is that fibers have been shown to allow increased asphalt binder contents and thus increase film thicknesses thereby increasing durability (**Thomas and Haiming, 1999**).

The results obtained from field studies show that the addition of fiber will help in produce more flexible mixtures that are also more resistant to cracking (**Saeed and Ali, 2000**).

The addition of fibers to asphalt concrete improved the fixation of the asphalt binder in the mix. This relates to less bleeding and improved skid resistance over unmodified mixtures of the same design. Fiber modification also allowed for an increase in film thickness, resulting in less aging and improved binder characteristics. The addition of fibers also resulted in the reduction of temperature susceptibility of asphalt mixtures (**Serfass and Samanos, 1996**).

A multitude of fibers and fiber materials are being introduced regularly in the market as new applications such as polyester fiber, asbestos fiber, glass fiber, polypropylene fiber (as shown in **Figure 1**), carbon fiber, cellulose fiber, etc. (**Saeed and Ali, 2000**).

OBJECTIVE OF THE STUDY

The objective of this study is to evaluate the effect of polypropylene fiber at different contents (0.1, 0.2, and 0.3) percent by weight of total mix within the dense graded mixtures (types A&B) on the mechanical and volumetric properties, vertical strain, indirect tensile strength and the modules of elasticity of these mixtures and compare the performance characteristics of the fiber modified mixtures with that of control mix without fiber.

MATERIALS
The materials used in this study are locally available and currently used in road construction in Iraq except polypropylene fibers which are available in local market in Baghdad.

Asphalt Cement
One grade of asphalt cement was used in this work including A.C (40-50) from Daurah refinery at different contents (4.0, 4.5, 5.0, 5.5, and 6.0) percent by weight of total mix.

Aggregate
One type of crushed aggregate was brought from the hot mix plants of Taj Al-Qethara Contracting Company. The source of aggregate is from Al-Nibaay quarry. Two gradations with a top size of (19 mm, 12.5mm) respectively were used according to State Corporation of Roads and Bridges **(SCRB, 2003**). The specification limits and selected gradation of HMA mixtures are presented in **Figures 3 and 4** respectively.

Mineral Filler
Protland cement was used as mineral filler which is obtained from Tasluga cement factory.

Polypropylene Fiber
High performance short 19mm polypropylene fiber (PPF) was used in this study as shown in **Figure 2**; it was brought from Fosrok Company. The physical properties of PPF are presented in **Table 1** (**Murat, 1983**).

TEST METHODS
The following tests were performed on the prepared laboratory samples to evaluate the performance of dense graded mixtures:

1. Resistance to Plastic Flow (**Marshal Method, ASTM D 1559**).
2. Standard Test Method for Percent of Air Voids in Compacted Dense Graded Mixtures, ASTM D 2041.
3. Indirect Tensile Strength, ASTM D 4123,
4. Creep test , and
5. Ultrasonic Testing BS 1881 Part 203.

PRESENTATION OF TEST RESULTS
1. Resistance to Plastic Flow (Marshall Test)
Marshall Methodology for mix design is used in this work as an indicator of resistance to plastic flow. Stability, and flow were tested for each specimen using ASTM D 1559 and the results are presented in **Figures 5 and 6** for mix type A and B respectively.

2. Calculation of the Percentage of Voids in Total Mix (VTM) in Each Compacted Specimen:
The bulk density and maximum theoretical specific gravity tests were conducted according to ASTM D 2726 and ASTM D 2041 respectively and the voids in total mix (VTM), voids filled with asphalt (VFA), and voids in mineral aggregate (VMA) of the different paving mixtures are calculated and presented with other Marshall test results in **Figures 5 and 6** respectively.

3. Effect of Asphalt Cement and Polypropylene Fiber Contents on Marshall Properties
In order to evaluate the variation of properties of dense graded mixtures with type A and B aggregate grading at different asphalt and PPF contents, five asphalt content (4.0, 4.5, 5.0, 5.5, 6.0) % by weight of total mix were selected according to SCRB with three contents of PPF, (0.1, 0.2,

0.3) % by weight of total mix and compare the properties of these mixtures. The effect of these variables is shown in **Figure 5 and 6** respectively as stated previously.

From the inspection of the results, the modified mixture with (0.3%) PPF and with type (A) aggregate grading improve the resistance to plastic flow with acceptable stability and volumetric properties values according to State Corporation of Roads and Bridges **(SCRB, 2003**) when compared with that of control mix without fiber.

The use of PPF at (0.1 and 0.2) percent with type (A) may be lead to bleeding of asphalt from surface because the resulting mix has an air voids less than the recommended value of (3-5) % at 5% asphalt content and more.

The use of (0.1%) PPF with type (B) aggregate grading gives the highest values of stability, resistance to plastic flow, and density when compared with control mix without fiber and mixes containing other polypropylene contents.

Also from the inspection of the results it's found that the addition of (0.1%) PPF to type B mixtures reduce the percent of air voids (VTM) in comparison with that in the control mix but the most values still outside the recommended values. Poor performance still as in the control mix when (0.2% and 0.3%) PPF were used. An increase in fiber content in the mixture followed an increase in the VTM this was probably due to greater surface areas to be coated. Fiber and fine aggregate (composes 70% of the mix) absorb binder and then leads to increase the voids in the mixture. In addition, fine mixtures with higher fiber contents might experience lower compact ability, leading to higher air void values.

4. Indirect Tensile Strength Test Results

In this study the indirect tensile strength test was conducted to evaluate the tensile properties of different asphalt concrete mixtures that prepared at optimum asphalt content for each PPF content and for both type A and B grading.

The test was performed at different temperatures include (5Cº, 15Cº, 25Cº, and 40Cº) and the results for both type of mix (A and B) are shown in **Figures 7 and 8** respectively.

The indirect tensile strength (ST) was then calculated as follows in accordance with ASTM D 4123:

$$ST = \frac{2\ Pult.}{\pi D t}$$

Where:

Pult. = Ultimate applied load,

t = Thickness of the specimen, and

D= Diameter of the specimen.

The addition of PPF resulted in the reduction of temperature susceptibility of asphalt mixtures. Mixtures containing polypropylene fibers were found to have higher tensile strengths and resistance to cracking. Adding PPF enables developing mixtures rich in bitumen and therefore displaying high resistance to cracking.

Mixtures containing polypropylene fibers of (0.3%) with type (A) aggregate grading were found to have higher tensile strengths and resistance to cracking over unmodified mixtures of the same design. Fiber modification at 0.3% allowed for an increase in film thickness, resulting in improved binder characteristics and the fixation of the asphalt binder in the mix.

Also the same results obtained when (0.2%) PPF with type (B) aggregate grading was used.

5. Creep Test Results

Creep is an important measure of modified asphalt performance, its ability to elastically recover deformation. Since asphalt pavement are designed to be flexible, they must quickly return to their original configuration after loading (**Muncy, and Prudhomme, 1987**).

The diametric – indirect tensile creep test has been used to determine the vertical strain of asphalt mixtures by measuring strain – time values. This test is performed on Marshall Specimens at corresponding optimum asphalt content (OAC) for each polypropylene content under a constant stress of (0.1Mpa). The specimen is loaded to static stress of 0.1 Mpa for 1 hour, and the deformation is recorded at certain time increments of (0.1 , 0.25 , 0.5 , 1 ,2 ,4 ,8 ,15 ,30 ,45 ,and 60 min). The load is then released, and the recovered strain for 1 hour is recorded, at the same periods. The vertical strain ϵ_{mix} is calculated by using the following formula:

$$\epsilon_{mix} = \Delta H / Do \text{ (mm/mm)}$$

Where:
ΔH= the total measured vertical deformation at a certain loading time (mm), and
Do=the original diameter of specimen (mm).
From the results of this test for aggregate grading type (A) showing in **Figure 9, 10 and 11**, the vertical strain tends to declined when the polypropylene fiber is added at 20C° and 40C°, but the samples without and with 0.1% and 0.2% PPF cannot resist the hottest temperature at 60C°. At this temperature the resistance to the deformation occurred at 0.3% PPF only while other samples tend to failed.
For type B aggregate grading, at 20C° and 40C° the best resistance to the deformation under the combined action of load and temperature occurs at 0.1% PPF as shown in **Figures 12 and 13**. **Figure 14** shows that at the hottest temperature (60C°) all samples with and without PPF tend to failed because this type of mix contains about 70% fine particles that make these mixes unable to carry the applied load at this high test temperature.

6. Ultrasonic Testing
The main advantage of this test is that it is nondestructive. In addition, the test can be performed on both laboratory-prepared specimens and field cores (**Rajas, and Yaun, 1999**).
The prepared specimens can be used to perform ultrasonic tests at 25C°. The elastic modulus of a specimen is measured using an ultrasonic device containing a pulse generator and a timing circuit, coupled with piezoelectric transmitting and receiving transducers. The timing circuit digitally displays the time needed for a wave to travel through a specimen. The receiving transducer, which senses the propagating waves, is connected to an internal clock. The clock automatically displays the travel time, (**t**) that can be used with the density of the specimen to calculate the constrained modulus, **Md,** as:

$$Md = \rho Vp^2 = \rho\,(L/t)^2$$

Where:
ρ: Density,
Vp: Compression wave velocity, and
L: Average length of the specimen.
t: Travel time.
Then the elastic modulus of the HMA specimens, E_d, can be determined from:

$$E_d = M_d \left[\frac{(1-2v)(1+v)}{(1-v)}\right]$$

The Poisson´s ratio, , can be assumed based on experience.
The test results in **Figure 15** shows that mixture containing (0.3%) polypropylene fibers with type (A) aggregate grading were found to have the higher elastic modulus over the control and other modified mixtures.

STATISTICAL MODELS FOR CREEP TEST

The effect of temperature, time, polypropylene content, and elastic modulus on vertical strain of dense graded mixtures is examined by descriptive statistical analysis.

The relationship between the dependent and independent variables was examined using the SPSS statistical package. The package was used to perform the required statistical analysis.

The results of the statistical analysis are presented in **Table 2**. The (R^2) obtained values are substantially high except for type B mix (unloading case) because the tested samples failed during the loading stage at 60C° as shown in **Figure 14** previously. This would suggest that the selected form of models is reasonably capable of producing results with adequate accuracy within the examined range of material properties and contents.

From the inspection of these models, the vertical strain reduced with the increase of PPF when type A mix is used. While for type B the reverse is occurred. This enhances the results of work plan that stated the optimum PPF occurred at 0.3% and 0.1% for types A and B respectively.

Where:

□mix: Vertical strain of dense graded mixtures, T: Testing temperature (C°),
PPF: Polypropylene fiber content (%), t: Time in minutes,
E_d: Elastic modulus of dense graded mixtures (MPa), and
SEE: Standard estimation error.

CONCLUSIONS

On the basis of the materials used and laboratory testing performed in this study, the following conclusions can be made:

1. In order to satisfy the requirements of desirable mixture properties for dense graded mixtures with types (A) and (B) aggregate grading, a relatively high optimum asphalt content (5.2%) and (5.1%) by weight of total mix respectively is required with optimum polypropylene contents (0.3%) and (0.1%) by the weight of total mix for types (A) and (B) respectively while (4.8%) and (4.7%) are required for the conventional dense graded mixtures without fiber types (A) and (B) respectively.
2. The use of polypropylene fiber as a modifier additive with types (A) and (B) aggregate grading has improved Marshall stability by (9%, and 7%), increased the resistance to plastic flow by (13%, and 12%) and decreased the air voids by (42%, and 26%) respectively in comparison with the conventional dense graded mixtures without fiber.
3. Mixtures containing (0.3%) and (0.2%) polypropylene fibers by weight of total mix with types (A) and (B) aggregate grading were found to have higher tensile strengths and less susceptible to low temperature effects over the control mix and as follow: an increase of (51%, 15%, 20%, and 10%) and (38%, 15%, 17%, and 10%) in indirect tensile strength (ST) at (5C°, 15C°, 25C° and 40C°) respectively.
4. The results of creep test showed that the PPF improved the mixture's performance against the anticipated permanent deformation. Type A mix with 0.3% PPF and type B mix with 0.1% PPF reduced the permanent deformation by (15%, and 33%) at 20C°and (38%, and 46%) at 40C° over the control mix respectively. While at 60C°, only the 0.3% PPF with type (A) resisted the action of the hottest temperature and all other mixtures failed early.
5. The PPF content reflected a remarkable effect on elastic modulus of dense graded mixtures. It's found that the use of 0.3% and 0.2% PPF with type (A and B) respectively improved the elastic modulus by 6% and 7% over the control mix.
6. The development of several models from laboratory test results obtained in this work can be used to evaluate the effect of different variables on the performance related to vertical strain of modified mixtures.
7. It is recommended to evaluate the effect of optimizing fiber properties (i.e., fiber diameter, length, surface texture, etc.) on the performance of dense graded mixtures.

ACKNOWLEDGEMENT
The author is grateful for the support of Highway and Transportation Engineering Department /College of Engineering/ University of Al-Mustansiriyah and Civil Engineering Department /College of Engineering/ Baghdad University.

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Table 1 Physical Properties of Polypropylene Fiber.

Form	Virgin Polypropylene Fiber
Specific gravity	0,91 gm/cm³
Fiber thickness	(18 and 30) microns
Young modulus	(5500-7000) Mpa
Tensile strength	350 Mpa
Melting point	160 C^{o}
Fiber length	19 mm

Table 2 Descriptive Statistical Models.

Mix	Case	Model	Adj. R^2	SEE
A	Loading	$\square mix = 10^{4.16} * (T)^{1.337} * (t)^{0.187} * (1+PPF)^{-0.849} * (E_d)^{-1.328}$	*0.930*	*0.077*
	Un-Loading	$Log(\square mix) = 0.132 + 0.014 (T) - 0.395 (PPF) - 0.001 (t)$	*0.95*	*0.042*
B	Loading	$\square mix = 10^{9.253} * (T)^{1.056} * (t)^{0.167} * (1+PPF)^{0.847} * (E_d)^{-2.464}$	0.899	0.077
	Un-Loading	$\square mix = 1.601 + 0.065 (T) + 1.744 (PPF) - 0.011 (t)$	*0.55*	*0.64*

Figure 1 Polypropylene Fiber Configurations.

Figure 2 Polypropylene fiber configuration that is used in this study.

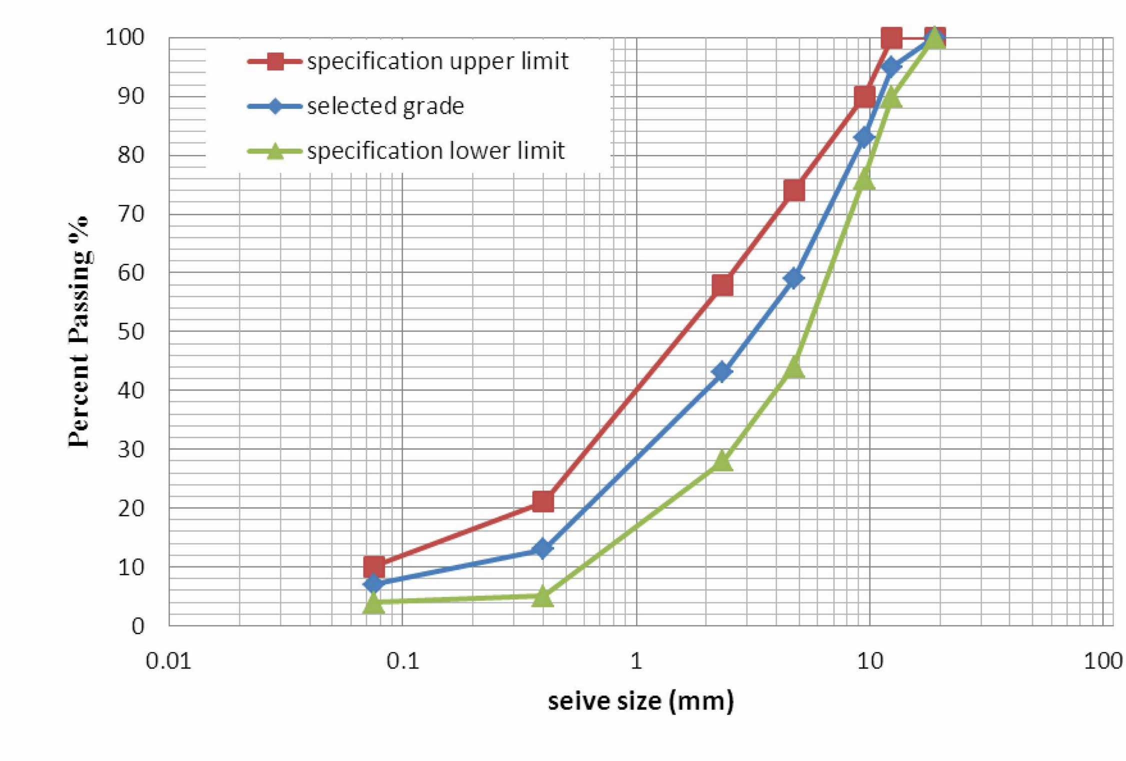

Figure 3 Specification limits and selected gradation of aggregate, type (A).

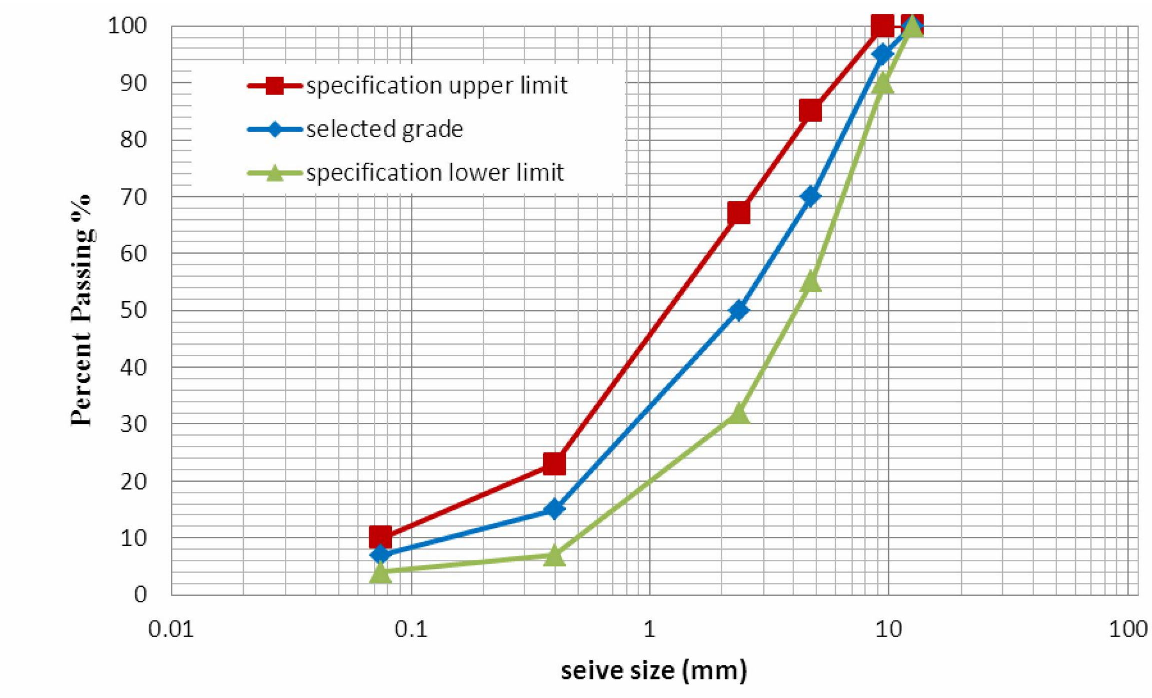

Figure 4 Specification limits and selected gradation of aggregate, type (B).

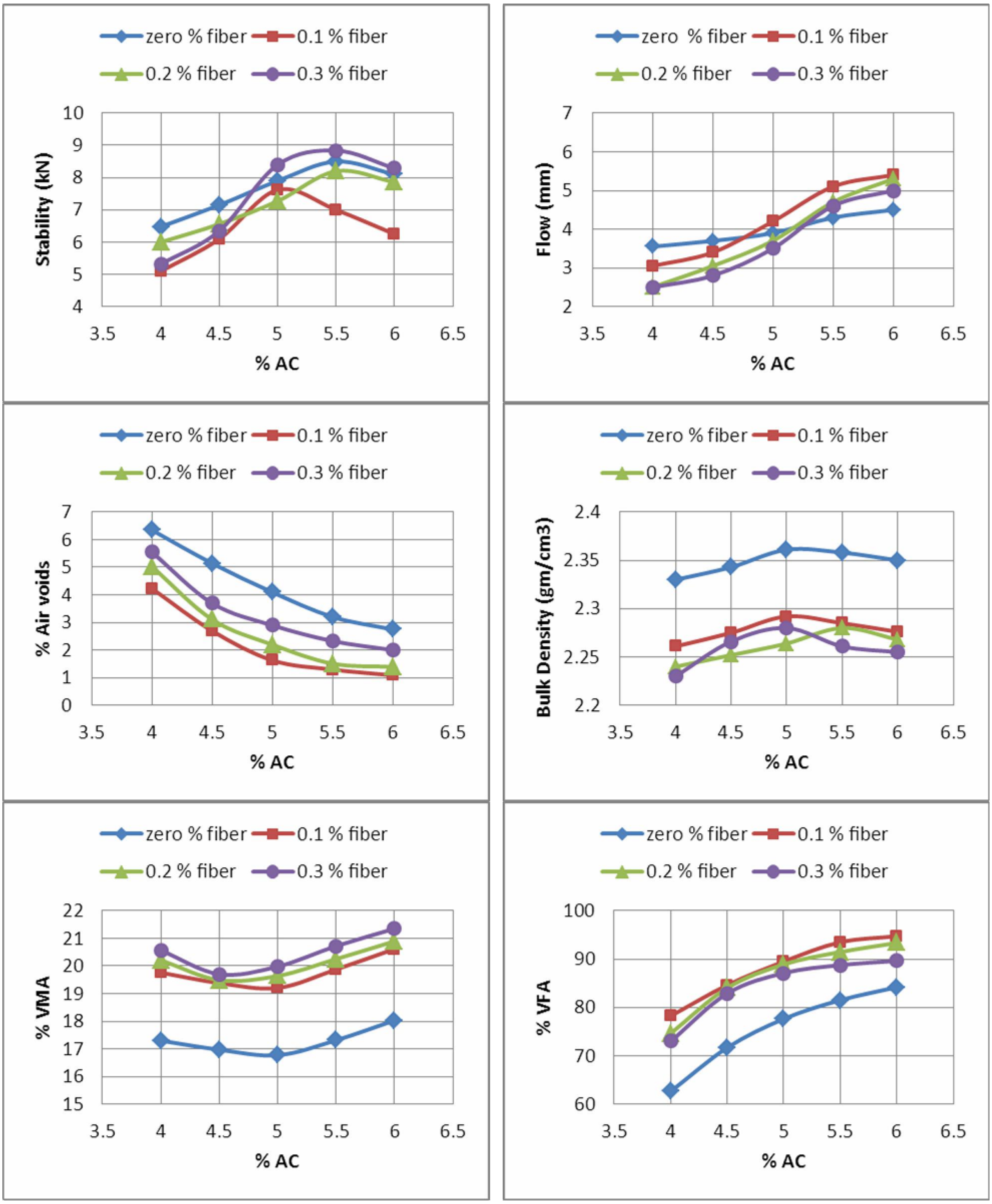

Figure 5 Effect of asphalt cement content and polypropylene content on Marshall properties of dense graded mixtures type (A).

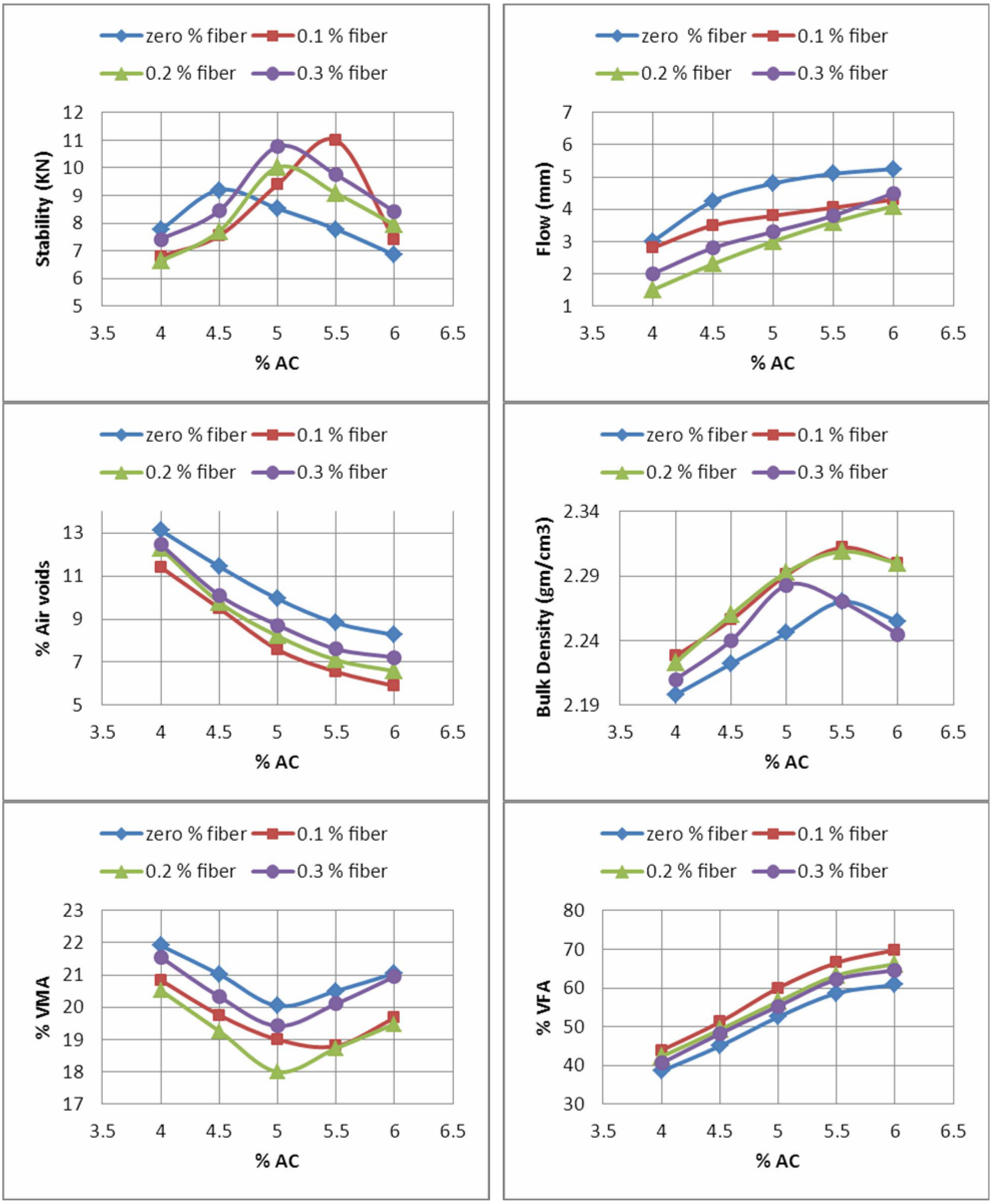

Figure 6 Effect of asphalt cement content and polypropylene content on Marshall properties of dense graded mixtures type (B).

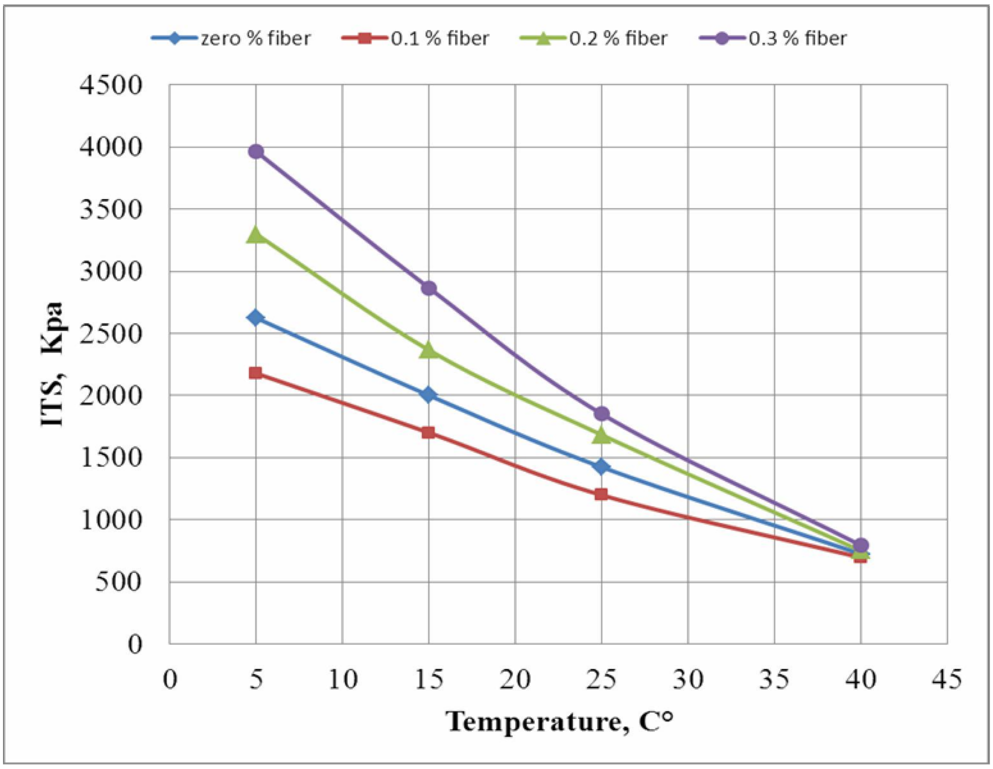

Figure 7 Effect of testing temperature on indirect tensile strength of dense graded mixtures type A.

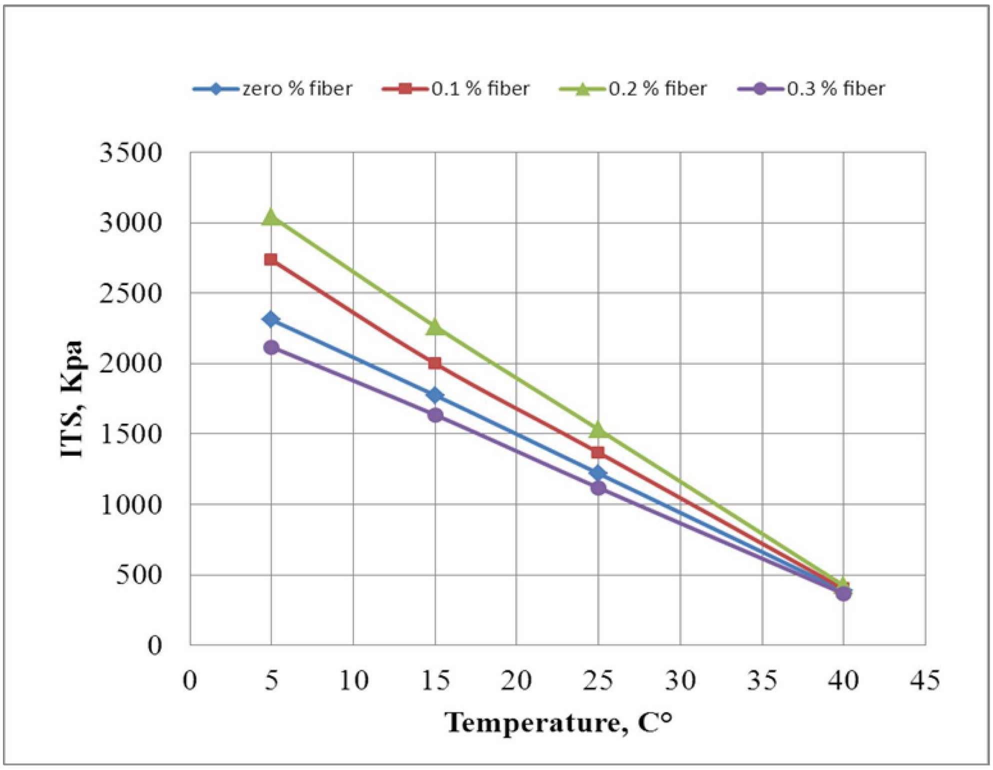

Figure 8 Effect of testing temperature on indirect tensile strength of densegraded mixtures type B.

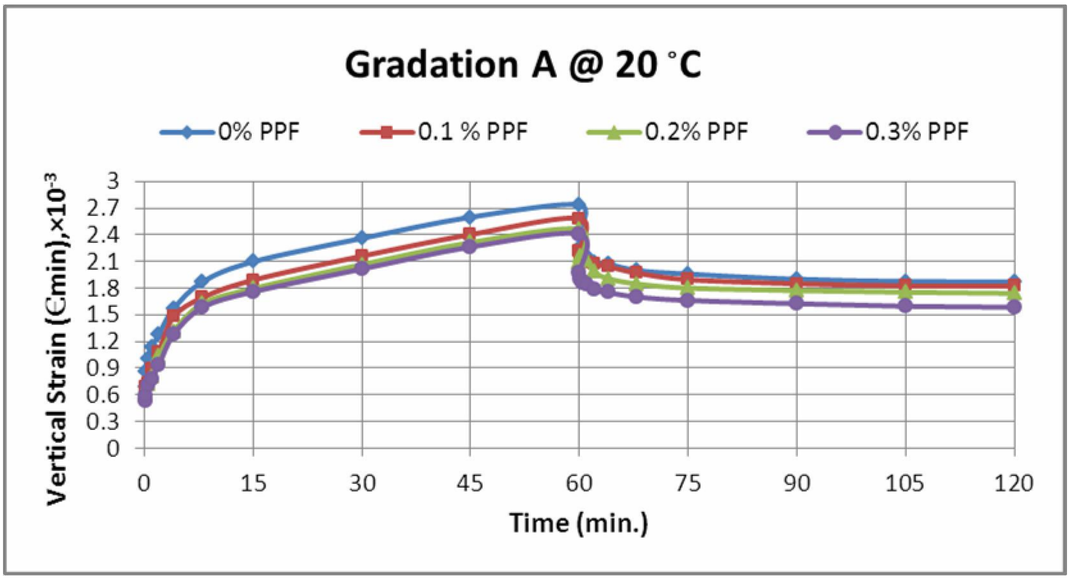

Figure 9 Effect of polypropylene content on strain- time relationship.

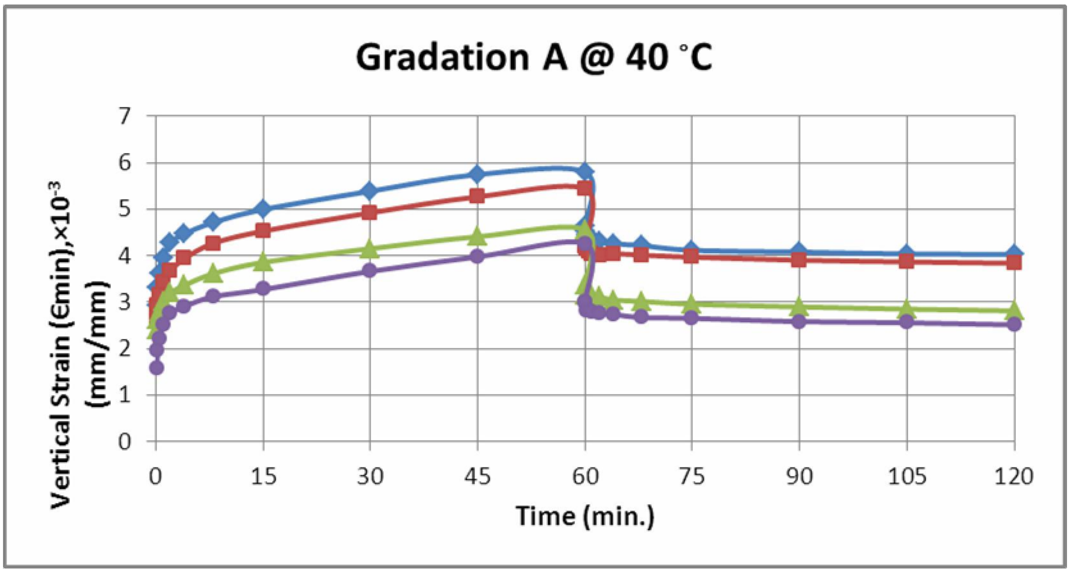

Figure 10 Effect of polypropylene content on strain- time relationship.

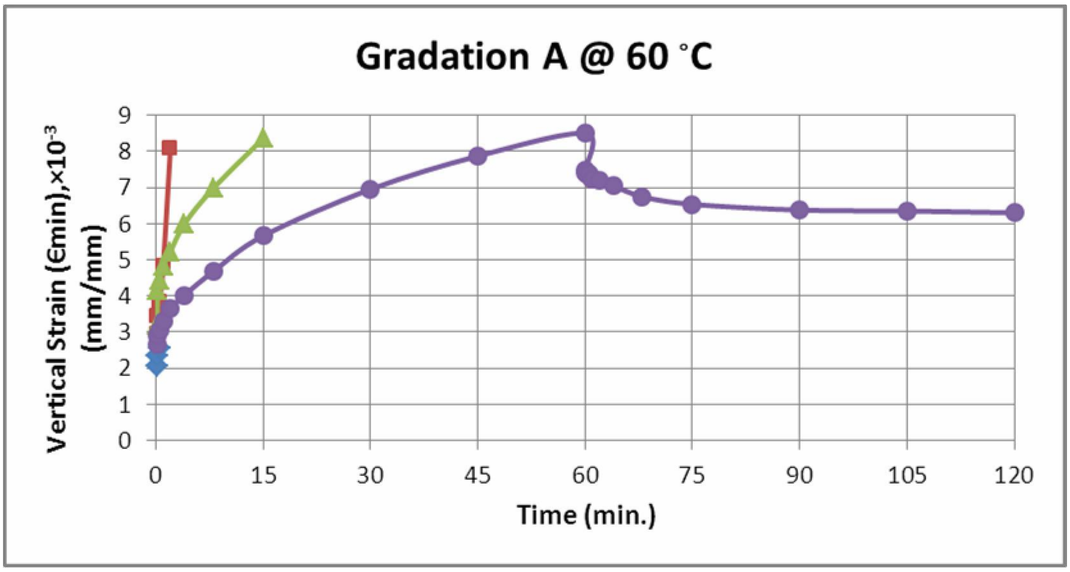

Figure 11 Effect of polypropylene content on strain- time relationship.

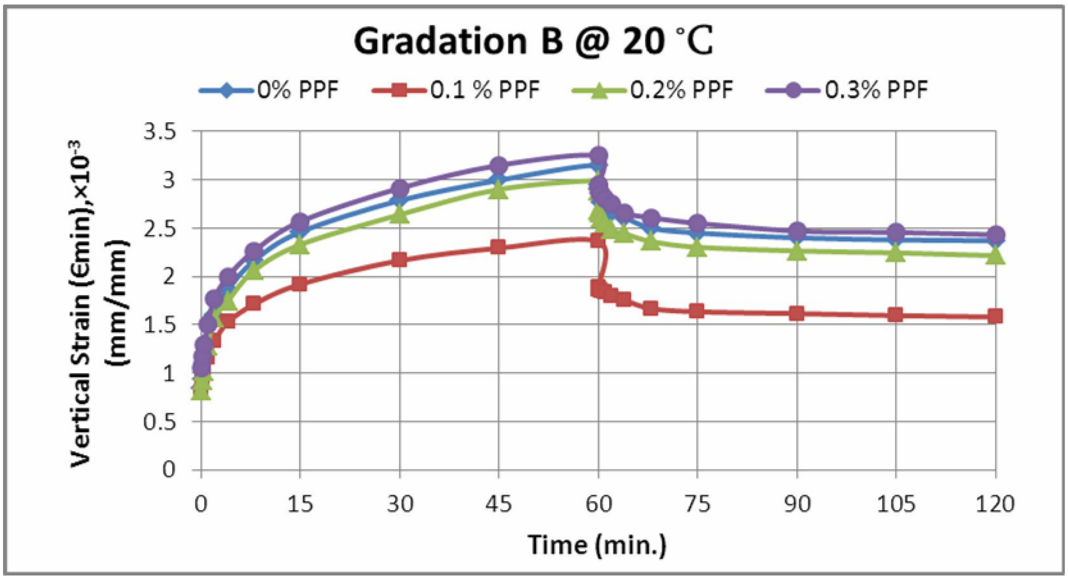

Figure 12 Effect of polypropylene content on strain- time relationship.

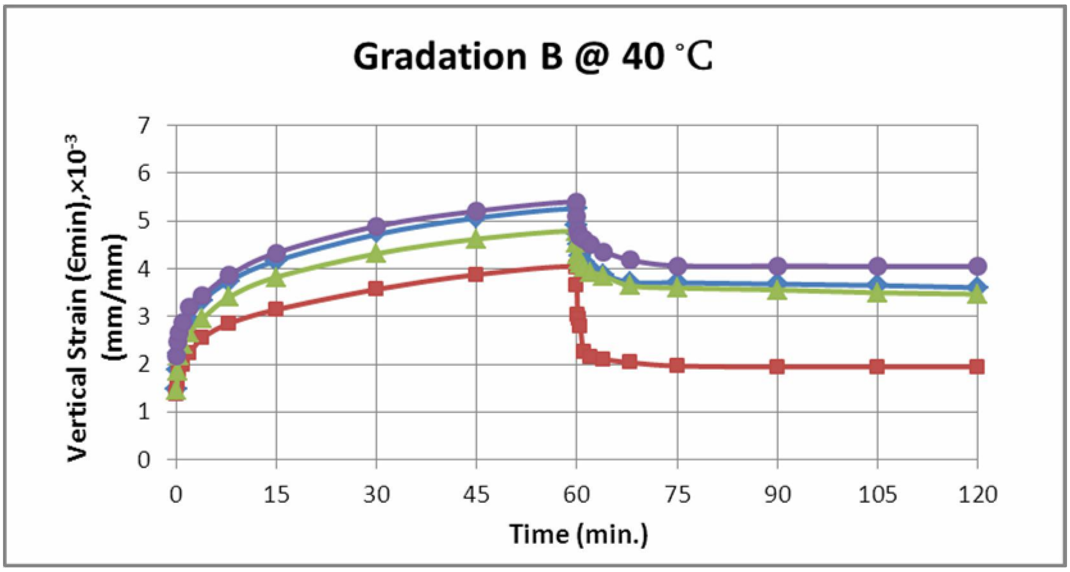

Figure 13 Effect of polypropylene content on strain- time relationship.

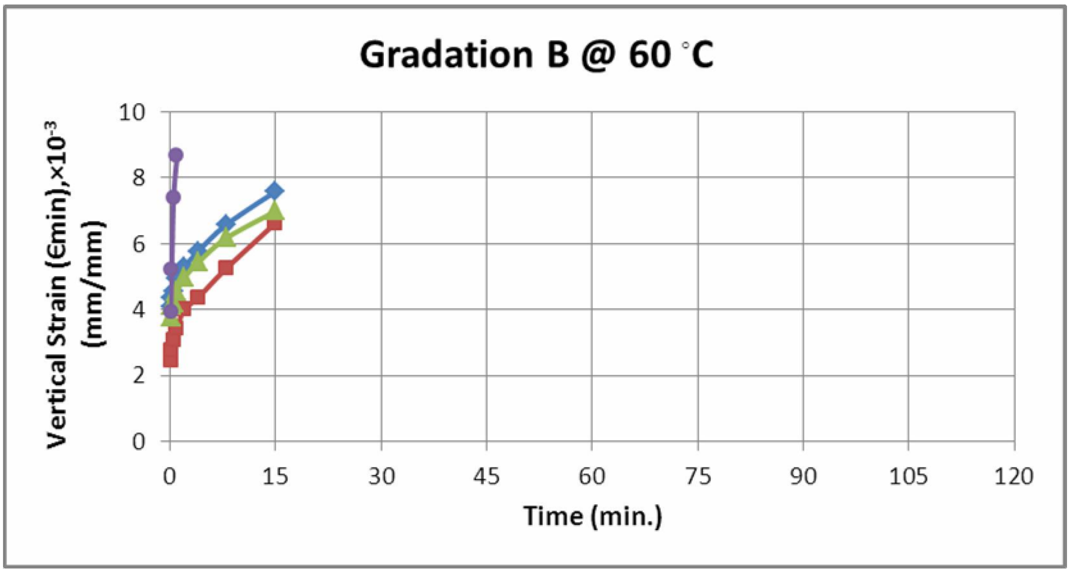

Figure 14 Effect of polypropylene content on strain- time relationship.

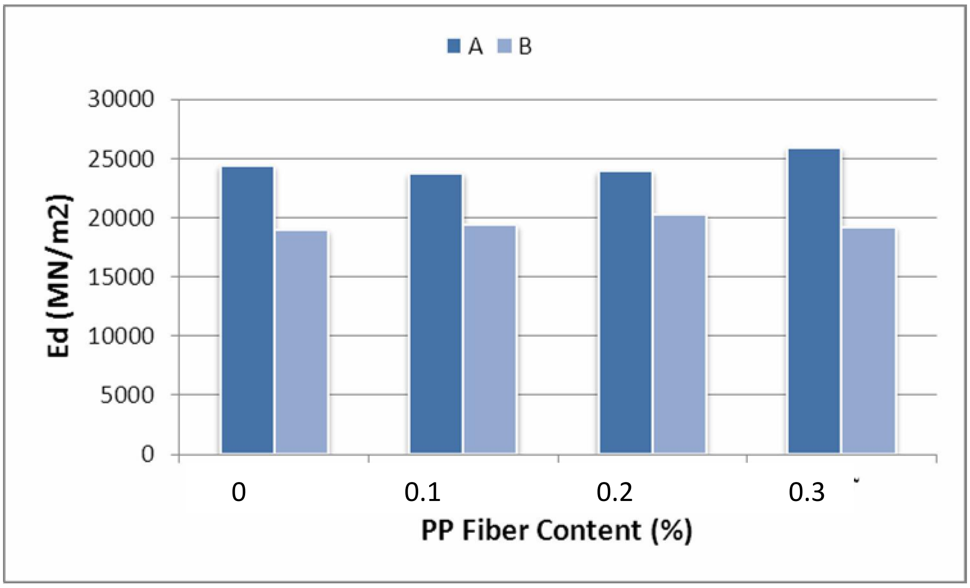

Figure 15 Effect of polypropylene content on elastic modulus of asphalt mixtures