Fracture characteristics of asphalt mixtures containing asphalt millings with geosynthetic fragments

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Abstract. The increasing cost of asphalt and environmental concerns have created a greater interest in exploring the possibility of incorporating higher percentages of reclaimed asphalt pavement (RAP) materials in asphalt mixtures. However, increasing the RAP content can adversely affect some of the properties of asphalt mixtures, including their cracking resistance potential. Consequently, finding a solution that accommodates incorporating higher RAP contents into the asphalt mixture is crucial. Moreover, geosynthetics has gained significant popularity as an anti-reflective cracking system in asphalt pavements, which may lead to the possibility of milling asphalt layers with geosynthetic interlayers. Thus, research studies need to be conducted to understand the characteristics and behaviour of RAP obtained from asphalt layers with geosynthetic interlayers (referred herein as GRAP). The objective of this study is to investigate the cracking characteristics of asphalt mixtures containing different percentages (0, 15, and 30%) of RAP and GRAP material using cross-shear tests. Results indicated that the addition of GRAP into the asphalt mixture by about 30% significantly improves the performance of asphalt mixtures against crack initiation and propagation compared to those asphalt mixtures containing only RAP. Overall, it can be inferred that the presence of geosynthetic fragments could increase the possibility of incorporating higher percentage of RAP in asphalt mixtures.

1 Introduction

Asphalt pavements have gained considerable recognition as a highly recycled material in the United States [1]. The reuse of reclaimed asphalt pavement (RAP), which comprises asphalt binder and aggregates, offer substantial cost savings and environmental benefits when incorporated into new asphalt mixtures. In a survey conducted by the National Asphalt Pavement Association (NAPA), it was reported that 76.9 million tons of RAP was effectively utilized in new asphalt mixtures during 2016, which resulted in substantial savings exceeding US $2 billion [2]. Despite the numerous economic and environmental benefits associated with reuse of higher percentages of reclaimed asphalt pavement in asphalt mixtures, state

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transportation agencies and local public agencies have imposed restrictions, limiting its usage to small percentages (20%) or none at all in their roadways [1]. On the other hand, previous laboratory and field research studies have demonstrated that asphalt mixtures with high RAP contents of up to 50%, can exhibit comparable performance to those containing only virgin materials (i.e., conventional asphalt mixtures). For instance, test sections at the National Center for Asphalt Technology (NCAT) test track, incorporating 50% RAP, outperformed sections that contained virgin asphalt mixtures, even after 5 years of heavy loading [3]. In contrast, Chen et al. [4] and Ma et al. [5] reported that high proportion of RAP can have a detrimental effect on the performance of asphalt mixtures, thus RAP levels should be maintained between 30-40% in asphalt mixtures. The utilization of higher quantities of RAP in new asphalt mixtures raises concerns regarding the potential increase in susceptibility to fatigue and low-temperature cracking over the lifespan of the pavement. This susceptibility is attributed to the aging and hardening of the asphalt binder present on the surface of RAP. Since 2000s, multiple research studies have been conducted to address the challenges associated with incorporating higher percentages of RAP in asphalt mixtures [1, 6, 7]. However, no practical solution to improve the fracture properties of asphalt mixtures with high RAP content has been determined yet.

On a different note, geosynthetics have demonstrated their effectiveness in significantly prolonging the lifespan of existing pavements. Geosynthetics provide multiple functions including reinforcement, stiffening, drainage, separation, and hydraulic barrier. By strategically placing geosynthetics at different levels within the pavement structure, notable benefits were observed, such as reduction in rutting and permanent deformation [8, 9], an improvement in fatigue life [10], and mitigation of reflective cracks [11, 12]. Moreover, utilization of geosynthetics within the asphalt and base layers of the pavement may lead to a reduction in the pavement thickness, thereby minimizing construction costs. Due to this widespread adoption of geosynthetic interlayers between the asphalt layers, there is a high possibility of milling asphalt layers containing geosynthetic interlayers during their rehabilitation. Thus, it is essential to investigate the properties of RAP obtained from such asphalt layers with geosynthetic interlayers. Although the existing literature on this topic is scarce or limited, it is crucial to acknowledge that as the utilization of geosynthetics in asphalt layers continues to gain traction, there is a potential for a higher occurrence of RAP that includes remnants of geosynthetic interlayers. Tran et al. [13] did explore such a topic, where they compared the properties of asphalt mixtures prepared with 30% RAP with and without geosynthetic fragments. They observed no significant differences in tensile strength, rutting, moisture damage and thermal cracking performance between the two mixtures. Recently, Saxena et al. [14] reported that RAP containing geosynthetics fragments (GRAP) can be used up to 50% and 30% in base and surface courses, respectively. They reported that indirect tensile strength and moisture susceptibility of asphalt mixtures containing GRAP is comparable to those containing RAP. However, there is still a lack of understanding on the influence of GRAP on fracture properties of asphalt mixtures. Thus, in this study, asphalt mixtures containing 0% (referred as control mixture), 15% and 30% RAP and GRAP materials were prepared and their fracture properties in terms of pre-cracking energy index and fracture energy index using the cross-shear test (under mode II/shear loading) is reported.

2 Materials

2.1 RAP and GRAP

The RAP and GRAP materials utilized in this study were obtained during the rehabilitation of United States (US) Highway 70/84 at Muleshoe, TX. The pavement structure consisted of multiple layers, including a limestone granular base and subbase with a combined thickness of 300 mm. Followed by an asphalt layer with 110 mm thickness that comprised of a 50-mm-thick bottom layer and a 60-mm-thick top layer, with a paving fabric placed at the interface between them. Both the top and bottom asphalt layers comprised a dense graded asphalt mix known as TY-C. The paving interlayer was a nonwoven geotextile that had a mass per unit area of 139 g/m^2. The primary purpose of incorporating the interlayer was to serve as both a stress relief and moisture barrier component within the pavement structure. The milling process performed during the roadway rehabilitation involved two stages. Initially, the top 50 mm of the 110 mm thick asphalt layer was milled and the reclaimed asphalt pavement (RAP) without any geosynthetic fragment was collected. Subsequently, the remaining 60 mm thick asphalt layer, which included a geosynthetic layer positioned at a depth of 10 mm from the previously milled surface, was milled and samples of reclaimed asphalt pavement with geosynthetic fragments (GRAP) were collected. The binder content of the collected materials was then determined, per AASHTO T164-22 [15] and observed to be 4.92% and 5.87%, respectively for RAP and GRAP materials.

2.2 Asphalt

In this study, the asphalt binder utilized was a Performance Grade (PG) 64-22, which was supplied by Ergon Inc., located in Austin, USA. The properties of asphalt binder have been determined by the manufacturer and the binder was reported to have a penetration value of 69, softening point of 52°C, and specific gravity of 1.01. Additionally, the binder exhibited a flash point of 330°C and a viscosity of 368 centistokes at 135°C, as measured using a rotational viscometer.

Limestone aggregates were used to prepare the asphalt mixtures in this study. The grain size distribution of virgin aggregates (VA) (forming control mix) used in this study is shown in Figure 1, which meets the TY-D surface mixture criteria specified in Item 341 of the TxDOT hot mix asphalt (HMA) aggregate specifications [16].

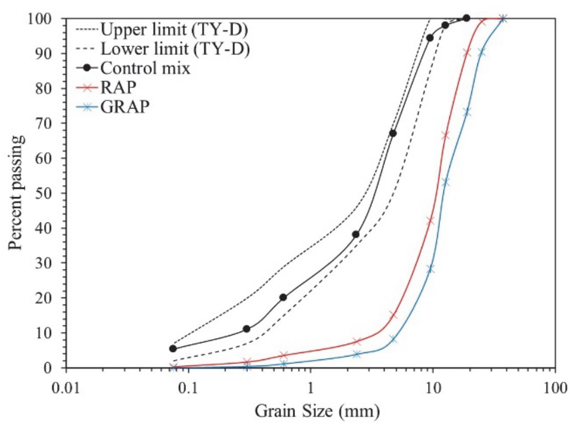

Fig. 1. Grain size distribution of aggregates used in this study.

3 Methodology

This research study comprises of four main stages. The first stage includes characterization of RAP and GRAP materials. Subsequently, optimum binder content of each mixture was determined using Superpave gyratory compaction method. Then, cylindrical specimens of 150 mm diameter containing different percentages (0, 15, and 30%) of RAP and GRAP materials were produced and trimmed to the size of cross-shear tests. Finally, cross-shear fracture tests (under mode II loading/shear loading) at room temperature were performed to determine the cracking performance of the prepared mixtures. Details of each stage is described in the following sub-sections.

3.1 Mix design and sample preparation

The first stage of the mix design included crushing of collected RAP and GRAP materials to reduce their sizes since the collected material were large and hence, could not be directly used for sample preparation. By crushing the material, large chunks of RAP and GRAP aggregates were broken down into smaller particles, ensuring better blending with virgin aggregates and homogeneity within the asphalt mixtures. The crushing process was performed in the laboratory using a modified Proctor compaction hammer, which involved repetitive dropping of a 4.5 kg weight from a height of 450 mm for about 100 times. The particle size distribution of RAP and GRAP materials after crushing is shown in Fig. 1. The figure demonstrates slight variation in the gradation curves of RAP and GRAP materials, which could be primarily attributed to the presence of geosynthetic fragments in GRAP material that resulted in GRAP material being coarser compared to the RAP material. Finally, to meet the gradation specifications of the TY-D surface course mixtures, blending of VA with RAP and GRAP material was performed. Five mixtures containing 0%, 15% and 30% RAP and GRAP material were prepared, which were denoted as: control mix (containing only VA), 15-85 RAP (containing 15% RAP and 85% VA), 15-85 GRAP (containing 15% GRAP and 85% VA), 30-70 RAP (containing 30% RAP and 70% VA), and 30-70 GRAP (containing 30% GRAP and 70% VA). It should be noted that the required quantities of RAP and GRAP material were separately added and blended with the required quantities of VA to satisfy the particle size requirements of TY-D asphalt mixture, as shown in Figure 2.

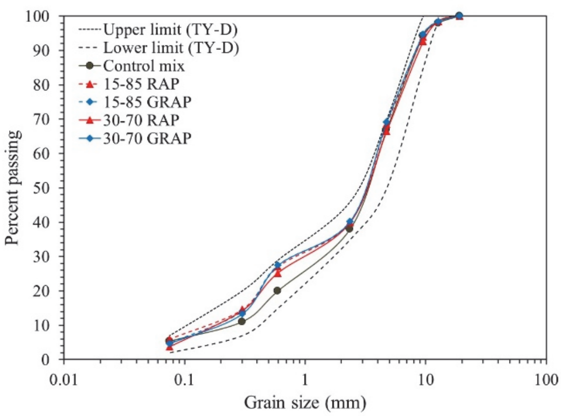

Fig. 2. Gradation of aggregate blends evaluated in this study.

Once the blends were prepared, the optimum amount of virgin binder required for the preparation of asphalt mixtures involving control mix, 15-85 RAP, 15-85 GRAP, 30-70 RAP and 30-70 GRAP was determined as 4.45%, 4.10%, 4.00%, 3.70%, and 3.55% by weight of total mixture, respectively. As expected, the RAP and GRAP mixtures required lesser virgin binder to achieve the optimum binder content compared to that with the virgin asphalt mix, due to the presence of aged binder on the surface of RAP and GRAP material. Additionally, these results also indicated that the asphalt mixtures comprising GRAP material required less virgin binder compared to those mixtures containing RAP or VA. This may be due to the presence of higher asphalt content in GRAP material, potentially resulting from the application of tack coat during the installation of geosynthetic interlayer.

For preparing the specimens, aggregates (whether natural or reclaimed) and binder were heated respectively at 110°C and 150°C for 2 hours. Subsequently, the virgin binder was added into the aggregate mixture at a temperature of 160°C and thoroughly mixed. The prepared mixtures (5 blends) were then transferred to an oven and heated to a temperature of 145°C for a duration of two hours. Once heated, the mixtures were carefully placed within a 150 mm dia mold and placed on a Superpave gyratory compactor and compacted to a height of 57 mm (corresponding to the desired target air void of 7%) based on the theoretical maximum specific gravity and required bulk specific gravity. Figure 3 shows the process of sample preparation including mixing of aggregates and binder (Fig. 3a), and compacted specimen (Fig. 3b). Subsequently, the compacted cylindrical specimens were saw-cut into brick shaped specimens (Fig. 3c), measuring 150 mm long (corresponding to the original diameter), 76 mm wide and 38 mm thick to perform cross-shear tests.

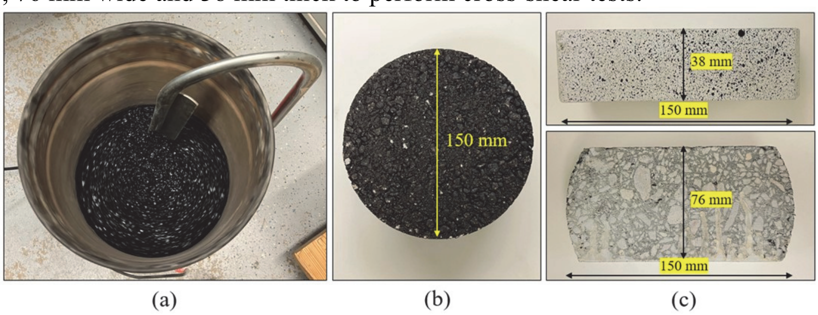

Fig. 3. Sample preparation: (a) mixing of aggregate and binder; (b) compacted specimen; and (c) final brick-shaped specimen for cross-shear testing.

3.2 Cross-shear test setup

The laboratory-based cross-shear test, as illustrated in Figure 4, serves as a simple and effective means of assessing the cracking resistance potential of hot mix asphalt mixes under mode II/shear loading. In this test, a specimen is securely bonded between two metallic plates, with one side (left) fixed and the other (right) mobile. A 5 mm gap between the top plates is designed to simulate the presence of transverse cracks or joints found in aged pavements when subjected to shear (mode II) loading. In this study, monotonic cross-shear test was conducted in a displacement-controlled mode at a rate of 7.68 mm/min, with an initial seating load of 100 N. Additionally, the load applied on the specimen was measured using load cell while horizontal and vertical displacements were measured by LVDT (see Fig. 4). The load was applied until the specimen fractured completely, i.e., when the resistance offered by the specimen became zero. Further details of the cross-shear test setup and methodology can be found in Roodi et al. [17] and Saxena et al. [18].

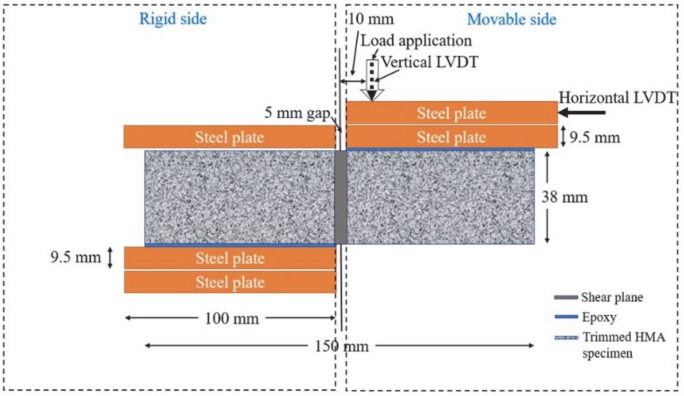

Fig. 4. Cross-shear test setup used in this study.

3.3 Parameters for fracture resistance characterization

In this study, the pre-cracking energy index ($PCE\ Index$) and fracture energy index ($FE\ Index$) were identified as fracture parameters for characterizing and distinguishing the cracking resistance potential of prepared mixes under monotonic cross-shear tests. The $FE\ Index$ was mathematically derived and defined as the ratio between the total fracture energy ($FE\ or\ G_D$) and the HMA shear strength (τ) multiplied by the shear strain (γ) at peak failure load per unit crack length (i.e., thickness of the specimen) during a monotonic loading test. The terms relevant to the derivation of Equation (1) are further explained in the subsequent text.

$$FE\ Index = \frac{G_D}{t\tau}\gamma \times 10^3 \tag{1}$$

where $FE\ Index$ is fracture energy index (dimensionless), the total fracture energy (G_D) was characterized as the amount of work required to create a crack of unit surface area in the specimen during monotonic cross-shear tests. This work is commonly denoted as $FE\ or\ G_D$ and was determined by calculating the area under the load versus displacement (L-D) curve, shown in Figure 5, and computed using Equation 2.

$$FE\ or\ G_D = \frac{1}{tb}\int_{w_1}^{w_2} f(x)dx \tag{2}$$

As given in Equation 2, G_D was computed as the integral of the load-displacement curve within the integral limits w_1 to w_2 shown in Figure 5 divided by the area of the cracked section ($thickness, t \times width, b$).
Fracture parameters, τ and γ in Equation 1 are defined as the HMA shear strength in kPa and shear strain in mm/mm at the peak failure load, respectively, and are as expressed in Equations 3 and 4, respectively.

$$\tau = \frac{P_{max}}{tb} \tag{3}$$

$$\gamma = \frac{\Delta_p}{t} \tag{4}$$

where, P_{max} is the peak shear load carried by the specimen, Δ_p is the displacement at peak load, t is the thickness of specimen (38 mm) and b is the width of specimen (76 mm).
Moreover, the fracture energy at the crack initiation stage (also known as pre-cracking energy) was calculated by Equation 5.

$$Pre-cracking\ energy\ (PCE) = \frac{1}{tb}\int_{w_1}^{\Delta_p} g(x)dx \tag{5}$$

where, $\int g(x)dx$ is the area under load-displacement curve up to peak load within the integral limits w_1 to Δ_p . Estimation of pre-cracking energy helped in the calculation of pre-cracking energy index ($PCE\ Index$), as provided in Equation 6.

$$PCE\ Index = \frac{PCE}{t\tau}\gamma \times 10^3 \quad (6)$$

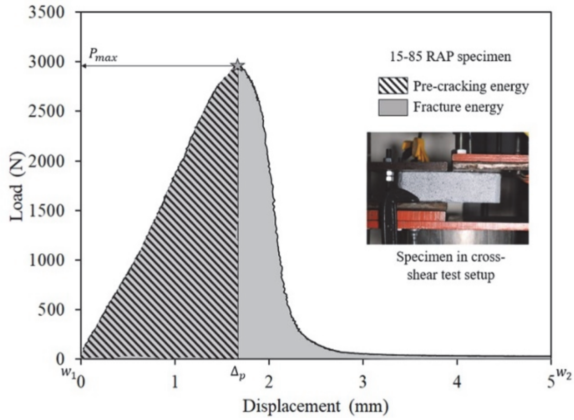

Fig. 5. Monotonic loading cross shear test L-D response curve.

4 Results and Discussion

The cross-shear tests performed on the prepared asphalt specimens containing VA, RAP and GRAP materials helped to understand the cracking resistance potential of the specimens under monotonic shear loading based on the energy dissipated by the specimens. The shear strength, defined as the maximum amount of shear stress that a material can be subjected to before fracture (refer to section 3.3), of the asphalt mixtures evaluated in this study were observed to be 744.98 kPa, 946.82 kPa, 835.17 kPa, 1349.64 kPa and 1171.75 kPa for control, 15-85 RAP, 15-85 GRAP, 30-70 RAP and 30-70 GRAP mixtures, respectively. The shear strength values for the RAP and GRAP mixtures were observed to be higher than that for the control mix, which can be attributed to the fact that RAP and GRAP material had aged and brittle binder on their surface which resulted in higher stiffness of specimens containing either RAP or GRAP. Amongst the RAP and GRAP mixtures evaluated in this study, 30-70 RAP had the highest shear strength followed by 30-70 GRAP, 15-85 RAP and 15-85 GRAP mixtures. Reduction in shear strength of GRAP specimens compared to that with RAP specimens, irrespective of their percentages might be due to the presence of geosynthetic fragments that might have reduced the stiffness of the mixture. However, contrary trends have been observed with respect to shear strain values. The shear strain (refer to section 3.3) which define the ductility and elongation potential of the specimens prior to the shear failure was found to be the highest for control mix (4.61%), followed by 15-85 GRAP (4.21%), 15-85 RAP (3.97%), 30-70 GRAP (3.58%) and 30-70 RAP (3.05%) mixtures. These results suggest that specimens containing GRAP failed at higher shear strain than those containing RAP, suggesting that geosynthetic fragments provide resistance to shear loading via elongation. Although the specimens containing RAP and GRAP material failed at lower shear strain compared to control mix, higher shear force was required to break the former specimens.

In monotonic testing, it is common to consider the peak load or maximum load at failure as an indicative parameter to assess the crack resistance capability of asphalt mixtures. However, Lee et al. [19] pointed out that relying solely on the resultant tensile strength (shear strength in our case), calculated based on the peak load and tensile strain (shear strain in our case), does not comprehensively represent the cracking resistance potential of HMA mixes. This limitation arises since both the tensile strength and peak failure strain are single-point parameters that fail to capture the complete loading history experienced by the asphalt specimen. To address this issue, Walubita et al. [20] suggested using fracture energy (FE) as it takes into account complete loading history and fracturing experienced by the specimen. In addition, the pre-cracking energy index ($PCE\ Index$) and fracture energy index ($FE\ Index$), which combines the tensile strength (shear strength in our case), peak failure strain, and pre cracking energy (PCE) or fracture energy (FE), has demonstrated effectiveness in representing the crack resistance potential of HMA mixes in laboratory settings [17]. The advantage of using the $PCE\ Index$ and $FE\ Index$ lies in their dimensionless nature, allowing for a more convenient comparison of the behavior of different mixes (refer to section 3.3). Thus, in this study, both the fracture parameters ($PCE\ Index$ or PEI and $FE\ Index$ or FEI) were evaluated for all the prepared mixes and their values are reported in Figure 6, with a focus on identifying whether the presence of geosynthetic fragments can improve the fracture resistance of asphalt mixture or not compared to those mixtures containing RAP. As shown in Figure 6, control mix had the highest PCE and FE Index values, followed by 15-85 GRAP, 15-85 RAP, 30-70 GRAP and 30-70 RAP mixtures. Reduction in the PCE and FE indices after addition of RAP and GRAP material was due to the higher stiffness of the blends, resulted by the presence of aged binder on the surface of the RAP and GRAP aggregates. Notably, the FE Index value of 15-85 GRAP and 30-70 GRAP specimens was reduced by 15.8% and 29.62% respectively compared to control mix, while reduction of 26.3% and 48.4% was observed respectively for 15-85 RAP and 30-70 RAP mixtures, suggesting that incorporation of GRAP improved the cracking resistance potential of asphalt mixtures in comparison to RAP mixtures. This might be due to the fact that when asphalt mixtures contain geosynthetic fragments or fibres, the fibres act as bridge on the cracks, thus impeding their propagation. Additionally, the presence of fibres in the mixtures enhances the coherence between the asphalt and aggregates, resulting in reduced stress concentration and improved performance [21]. Similar behaviour of asphalt mixtures has been observed by Ziari et al. [7], where the fracture resistance of asphalt mixtures improved by addition of 0.12% of glass fibres. Consequently, we can say that fibres play a significant role in enhancing the resistance of asphalt mixtures against crack initiation and propagation. Based on PCE and FE Index results, it can also be inferred that as the percentage of GRAP material increase in the mixtures, the resistance to cracking compared to the RAP mixtures also increases. For example, 15-85 GRAP mixture was found to have an improvement of 14.2% in FE index value compared to 15-85 RAP mixture. However, this improvement in FE index value increased to 36.4% for 30-70 GRAP mixture, compared to 30-70 RAP mixture. It should also be noted that 30-70 GRAP mixture had almost similar FE index as that of 15-85 RAP mixture, where 30-70 GRAP mixture had only 4.5% reduction in FE index value compared to 15-85 RAP mixture. This suggests that at higher percentages of GRAP material, large quantity of geosynthetic fragments become available in the blend which serve as a bridge on the crack and delay specimen failure. Moreover, based on the PCE and FE index results, it can also be said that presence of geosynthetic fragments can lead to the usage of higher percentage of RAP in the preparation of HMA mixes.

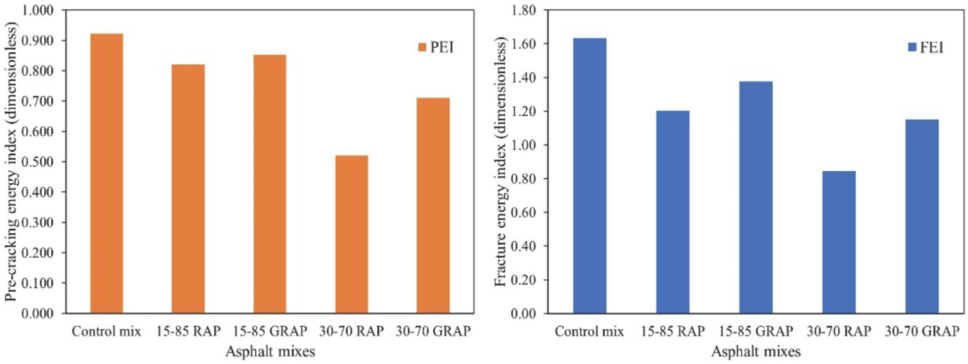

Fig. 6. Results of: (a) pre-cracking energy index; and (b) fracture energy index, for specimens containing 0%, 15% and 30% RAP and GRAP materials.

5 Conclusions

This study presents the characteristics of reclaimed asphalt pavement with (GRAP) and without (RAP) the presence of geosynthetic fragments and their impact on cracking performance of asphalt mixtures. In this regard, different percentages (0%, 15% and 30%) of RAP and GRAP material were incorporated into asphalt mixtures, and monotonic cross-shear tests were conducted at room temperature. The following conclusions can be drawn from this study.

- Reduction in the pre-cracking energy and fracture energy indices of asphalt mixtures with the addition of RAP and GRAP material compared to control mixture was due to the higher stiffness of the blends, resulted by the presence of aged binder on the surface of RAP and GRAP materials.
- The fracture energy required to crack asphalt mixtures containing GRAP material remained superior compared to those mixtures containing RAP material. This might be due to the presence of geosynthetic fragments or fibres in the former mixtures.
- With the increase in GRAP percentage in the blend, the resistance to cracking also increased compared to blends containing RAP material at any given percent replacement of VA.

Overall, it can be inferred that the presence of geosynthetic fragments in RAP materials improves the cracking performance of asphalt mixtures under shear (mode II) loading. In addition, GRAP material reduces the negative impact (i.e., less cracking resistance) of RAP material, which eventually implements higher usage of RAP containing geosynthetic fragments (GRAP) in asphalt mixtures.

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