Evaluation of Geosynthetic-reinforced Asphalt Milling Characteristics and Suitability as Pavement Base Course

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ABSTRACT

The use of reclaimed asphalt pavement (RAP) as roadway base course has provided both, environmental and economic benefits leading to sustainable pavement construction practices. Specifically, reuse of milled asphalt layers in pavement construction reduces the requirement of virgin aggregates (VA) and the associated cost. On the other hand, due to the possibility of milling asphalt layers that contain geosynthetic interlayers, studies have been carried out to understand the characteristic and behavior of RAP obtained from geosynthetic-reinforced asphalt, which is referred herein, as GRAP. The objective of this research is to investigate the suitability of reusing the GRAP as pavement base course. Accordingly, blends of 50% RAP and 50% VA base course material, and 50% GRAP and 50% VA were evaluated, as well as 100% VA. The laboratory evaluation of different blends included determination of particle size distribution, moisture-density relationship, coefficient of permeability, water absorption and bitumen content, and fragmentation value. Comparison of characteristics of different blends evaluated in this study suggest RAP containing geosynthetic fragments exhibited similar behavior compared to only RAP. Additionally, the results from this investigation indicate that both RAP and GRAP blends with VA exhibited adequate workability and properties, indicating their potential use as pavement base course material.

INTRODUCTION

The practice of milling the pre-existing asphalt surfaces, either partially or completely prior to the placement of the hot mix asphalt (HMA) overlay is the most common and traditional flexible pavement rehabilitation technique. During the asphalt milling process, large quantities of material including asphalt that are analogous to an aggregate-sized particle are generated, which is known as recycled asphalt pavement (RAP). RAP has been used in infrastructure applications since 1930 (Texas Report 1272-1S, 1994) with the aim of reducing the use of non-renewable aggregates in the roadways. The use of RAP as an alternative material is certainly a sustainable construction, since the need of excavating or producing raw materials for construction, their handling, transportation and storage can be minimized, which in turn minimize the energy consumption and impact of construction activity on the environment.

The Federal Highway Administration (FHWA) estimated that 100.1 million tons of asphalt pavements are milled off each year during resurfacing and widening projects (Thakur and Han 2015). RAP is mostly used to produce new asphalt mix for the base courses, and as a replacement of granular material in base and subbase courses, as well as in the shoulders, parking lots, bicycle paths, gravel road rehabilitation, residential driveways, trench backfill, and embankments among others. The Texas Department of Transportation (TxDOT) promotes using RAP in many pavement management strategies, such as hot recycling for new asphalt surfaces, shoulder surfacing and extra widening of roadways. In addition, warm and cold recycling of RAP includes usage of RAP as base or sub-base aggregate and as a backfill in retaining walls. Recently, several developments in the incorporation of RAP bases for environmentally friendly roadway applications have been demonstrated. Hopp et al. (2015) opines that there is a potential for significant economic benefits if RAP is used in base and subbase applications, i.e., approximately 30% in material cost savings could be realized with a 50% replacement of virgin aggregates (VA) with the RAP. Numerous researchers (e.g., Highter et al. 1997; Bejarano 2001; Guthrie et al. 2007; Abdelrahman et al. 2010; Cosentino et al. 2012; Seferoglu et al. 2018; Plati and Cliatt 2019) conducted laboratory studies on suitability and evaluation of RAP as a roadway base material that included moisture-density characteristics, California Bearing Ratio (CBR), unconfined compressive strength (UCS), shear strength characteristics, and resilient modulus. Plati and Cliatt (2019) demonstrated that both 100% RAP and 50% RAP-50% VA blends produced modulus values similar to that of conventional (100% VA) blends. Overall, most of the studies suggest that RAP blended with VA and/or stabilized with chemical additives can be a potential roadway base. However, few studies have reported contradictory results regarding the RAP blends' mechanical behavior. While, it is important to note that the RAP behavior depends on multiple parameters including their particle size gradation, bitumen content of RAP and percentage of RAP mixture included in the blends (Seferoglu et al. 2018).

On the other hand, geosynthetic interlayers have been very widely installed within the asphalt layers mainly to minimize reflective cracking (Kumar and Saride 2017; Saride and Kumar 2019); minimize permanent deformations and strains (Correia and Zornberg 2016; Kumar et al. 2021a, 2022); and enhance fatigue performance (Kumar et al. 2021b) of asphalt pavements. However, such conditions may lead to the possibility of milling asphalt layers that may contain geosynthetic interlayers. Hence, experimental research studies on the topic of geosynthetic-reinforced asphalt milling need to be conducted to understand the characteristics and behavior of RAP obtained from milling such asphalt layers reinforced with geosynthetic interlayers. While this topic is quite new or rather very limited literature exists, it is important to note that with the growing trend of incorporating geosynthetics within the asphalt, there is a possibility for an increase in the occurrence of RAP that contains remnants of geosynthetic interlayers. The question of whether the geosynthetic-reinforced asphalt millings affect the engineering performance of an asphalt mix containing RAP with geosynthetic fibers has been raised by Gu et al. (2021). Furthermore, discussions of whether geosynthetic-reinforced asphalt is "millable", whether geosynthetics tear apart or not during milling or if they interfere with the milling process have become more frequent concerns to the asphalt pavement community, while this is a rarely explored topic. However, Tran et al. (2012) did explore such a topic of milling the geosynthetic-reinforced asphalt layers. In addition, they compared properties of asphalt mixtures prepared using 30% RAP (without geosynthetics) and 30% RAP containing a geosynthetic reinforcement obtained from their study, separately. They reported that there were no significant variations between the two asphalt mixtures, in terms of their tensile strength characteristics, rutting performance, moisture damage, and thermal cracking analysis. On the other hand, Gu et al. (2021) highlighted that a 30% RAP containing milled polypropylene fabric had excellent resistance against moisture damage, rutting and thermal cracking conditions. In addition, they reported that the performance of asphalt mixtures containing RAP with geosynthetic fibers were quite similar to that of a conventional asphalt mixture without any RAP.

In summary, the evaluation of millability and recyclability of geosynthetic-reinforced asphalt millings are very limited in number, which needs more attention. In this regard, this study aims at evaluating the characteristics of geosynthetic-reinforced asphalt millings, referred herein as GRAP, and their suitability as a roadway base. Specifically, different blends including VA, RAP, and GRAP have been evaluated under laboratory conditions, in this study. The evaluation includes determination of particle size gradation, moisture-density relationship, coefficient of permeability, water absorption, bitumen content and fragmentation value.

MILLING AND SAMPLE COLLECTION

The geosynthetic-reinforced asphalt millings and the conventional RAP were collected from an ongoing rehabilitation project along US70/84 at Muleshoe, TX that required removal of asphalt layers completely and placing new asphalt layers. The pavement structure (see Fig. 1a) comprised of limestone granular base and subbase layers with a combined thickness of 300 mm and an asphalt layer with a total thickness of 110 mm that consisted of a 50 mm thick bottom layer and a 60 mm thick top layer with a paving fabric at their interface. A dense graded asphalt concrete referred as TY-C was adopted in both the top and bottom asphalt layers. Until 1995, the roadway had only 50 mm thick asphalt layer and during the pavement rehabilitation process in 1995, a paving fabric was installed prior to the placement and compaction of the 60 mm thick asphalt overlay. The paving fabric, used as stress relieving interlayer, was a polypropylene nonwoven geotextile. The milling operation comprised of two stages: first, milling the top 50 mm of the 110 mm thick asphalt layer to collect the RAP without any geosynthetic. Next, the remaining 60 mm thick asphalt layer comprising geosynthetic at a depth of 10 mm from the previously milled surface was milled to collect the GRAP samples. Figure 1 shows the roadway profile prior to the milling (see Fig. 1a) and the roadway profile after the milling operation (see Fig. 1b).

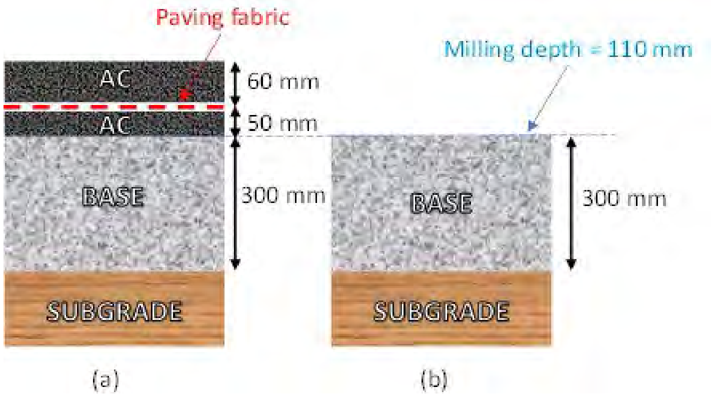

Fig. 1. Road profile: (a) before milling; (b) after milling.

The milling operation was completed using a cold milling machine and no detrimental effect was observed during the process of milling geosynthetic-reinforced asphalt. The fibers/pieces of milled geosynthetic were evenly distributed in the RAP. Figure 2 shows the process of milling the asphalt with and without geosynthetic interlayer to collect the RAP and GRAP samples in this study. As shown in the figure, the asphalt was milled and loaded via conveyors onto the dump truck and then transported to the stockpile. Samples were then collected from the stockpiles for the laboratory evaluation conducted in this study. Figure 3 shows the GRAP mixture consisting of geosynthetic fibers/pieces, and it can be observed that the geosynthetic pieces have asphalt mastic glued around them, which maybe crushed to match the grain size gradation requirements.

Fig. 2 - Milling operations to collect RAP and GRAP samples at US70/84 (July 2022).

Fig. 3 – GRAP samples collected in this study.

MATERIALS AND METHODS

Reclaimed Asphalt Pavement (RAP)

Control RAP and GRAP samples collected from the stockpiles were completely dried out to identify the necessity of crushing them before their characterization. Crushing process was conducted in the laboratory using the modified Proctor compaction hammer that included repeatedly dropping 4.5 kg weight from a height of 450 mm for 100 times. Figure 4 presents the sample collected from stockpile (Fig. 4a), which is being crushed in the laboratory (Fig. 4b), and the crushed GRAP sample used for characterization (Fig. 4c). The crushed RAP and GRAP samples were sieved to determine their gradation curves as presented in Fig. 5. The sieve analysis helped to identify RAP particle sizes and whether GRAP required screening the geosynthetic fibers. As shown in the figure, the gradation curves for RAP and GRAP varied slightly due to the presence of geosynthetic pieces and the asphalt mastic around them, which eventually led to a coarser gradation for GRAP in comparison with RAP samples tested in this study.

Figure 4. (a) GRAP sample collected from the stockpile; (b) GRAP crushing in the laboratory; and (c) Crushed GRAP sample.

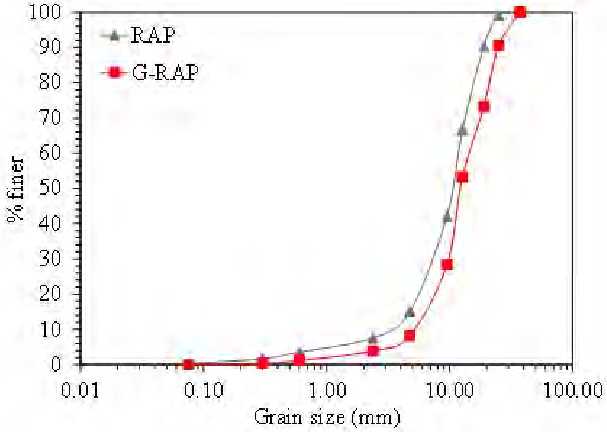

Figure 5. Particle size distribution curves of crushed RAP and GRAP.

During the sieve analysis of GRAP samples, fragments of geosynthetics were observed only up to 12.7 mm sieve and no traces were found thereafter, as shown in Figure 6. This condition maybe due to the reason that geosynthetic pieces were larger in size and additionally, the asphalt mastic around them increased their size. On the other hand, based on the gradation curves of RAP and GRAP material, additional VA material was blended separately to match the gradation requirements of granular road base.

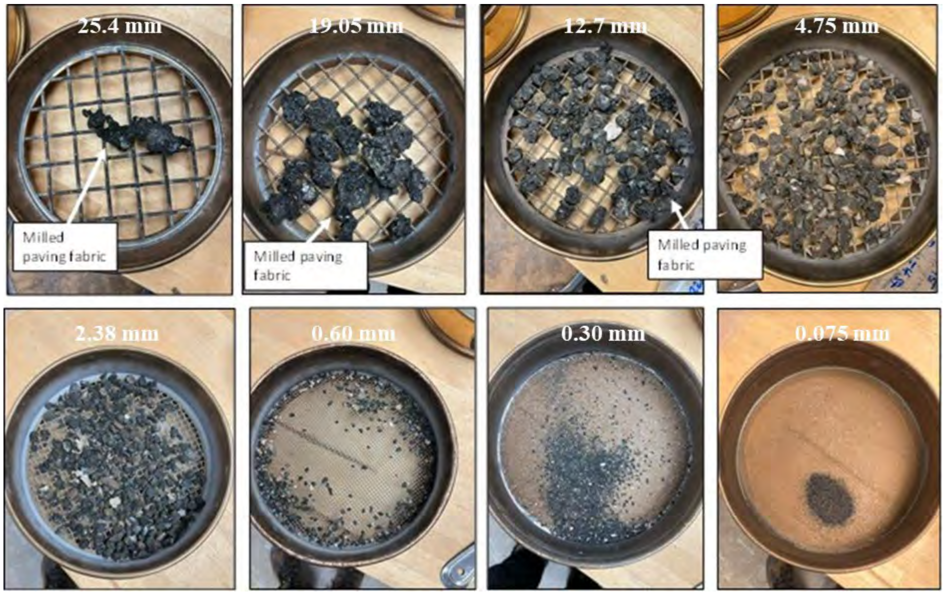

Figure 6. Overview of GRAP sieving and fragments of milled geosynthetic.

Virgin aggregate-RAP mixtures

Three different blends including VA, GRAP and RAP were investigated in this study to evaluate their suitability as a roadway base (see Fig. 7). Specifically, 50%RAP-50%VA (Fig. 7c) and 50%GRAP-50%VA (Fig. 7b) blends were developed and characterized along with a 100% VA blend (Fig. 7a) for comparisons. The VA material adopted in this study mainly comprised limestone aggregates and was obtained from Marble Fall Quarry - Texas Material in Texas, per AASHTO requirements. The RAP-VA and GRAP-VA mixtures were blended to meet gradation specifications (TxDOT, 2014) and are referred herein as 50-50 RAP, 50-50 GRAP mixtures. Figure 8 shows that gradation curves for all the three different blends of materials investigated in this study along with the upper and lower gradation limits for a roadway base. As shown in the figure, the different blends investigated in this study satisfy the base course gradation requirements, per TxDOT: Item 341 (TxDOT, 2014).

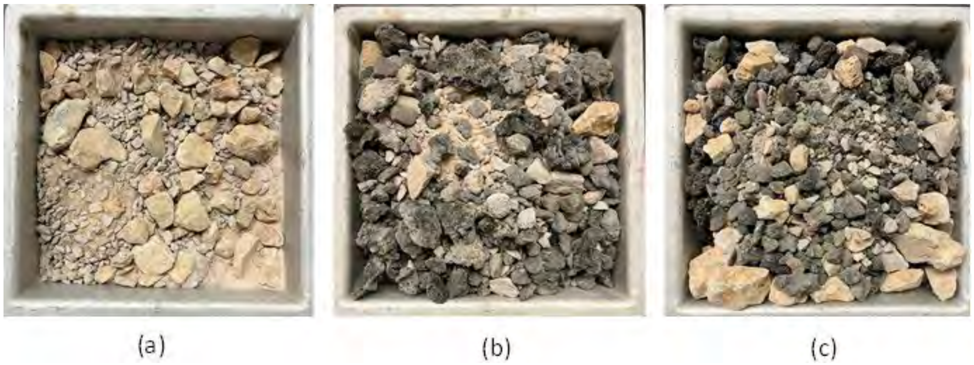

Figure 7. Investigated materials: (a) virgin aggregate; (b) 50-50 GRAP; (c) 50-50 RAP.

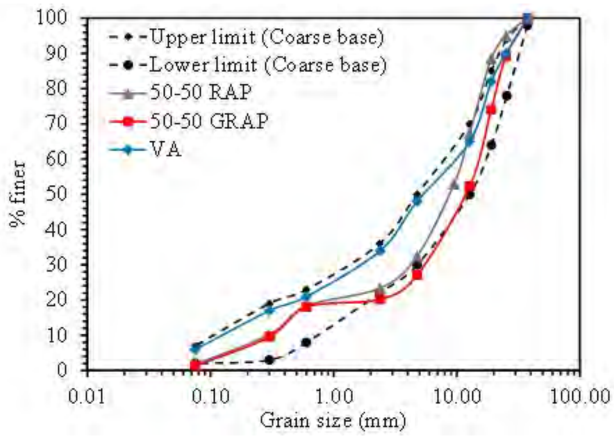

Figure 8. Investigated material gradation curves and course base limits.

Testing Program

The testing program included characterizing the RAP-VA and GRAP-VA blends along with VA blends for comparison. The characterization included determining the moisture-density relation, permeability characteristics, water absorption and binder content in RAP and GRAP, and fragmentation test results. The moisture-density characteristics for VA, 50-50 RAP, and 50-50 GRAP blends were determined using modified Proctor tests, per AASHTO T 180. Specifically, a hammer of 4.5 kg was lifted and dropped from a height of 450 mm, to compact the material in five equal layers with about 56 impacts per layer.

Permeability characteristics of VA, 50-50 RAP and 50-50 GRAP blends were evaluated, per ASTM D2434. Consequently, a constant head permeability test method was chosen for determining the permeability coefficient using a cylindrical sample with 152 mm diameter and 254 mm height. Samples were compacted considering 100% degree of compaction. Figure 9 shows the different samples during the constant head permeability test: VA (Fig. 9a), 50-50 RAP (Fig. 9b) and 50-50 GRAP (Fig. 9c).


(a) (b) (c)

Figure 9. Permeability tests of investigated materials: (a) Virgin aggregate; (b) 50-50 RAP; (c) 50-50 GRAP.

Water absorption value presents the ability of an aggregate to absorb bitumen. In this study, water absorption tests were conducted on VA, 50-50 RAP and 50-50 GRAP blends, per AASHTO T85. Specifically, about 3 kgs of sample was measured and immersed in water for about 24 hours, removed after 24 hours and surface dried before measuring their weight again. Finally, the surface dried samples were completely dried in the oven and weighed again. On the other hand, bitumen extraction tests were conducted only on RAP and GRAP samples, per AASHTO T164. In the case of GRAP, pieces of large geosynthetics were manually removed to determine the binder content of the surrounding aggregate particles. Figure 10 shows the bitumen extraction test used in this study.

Figure 10. Bitumen extraction test.

The RAP samples evaluated in this study contained fragments of geosynthetic, hence the fragmentation test was conducted, per RILEM TC237-SIB technical committee recommendation (Tebaldi et al. 2019) to evaluate the influence of geosynthetic fragments on aggregate quality after impact and temperature variations. The fragmentation test was conducted using a modified Proctor setup (per ASTM D1557 and AASHTO T180) on a fractioned single size aggregate material that was subjected to a series of standard impact loads at various temperatures. The fragmentation test measures a particle's resistance to fragmentation after being subjected to a series of shocks from the impact of a steel mass (rammer) being dropped onto a constrained sample inside a cylindrical steel mold. The amount of material passing through a 1.6 mm sieve is then measured. As a result, the coefficient of fragmentation is defined as the ratio of the weight of the material passing through 1.6 mm sieve after impact and the weight of the material before impact. This test is recommended to be performed with aggregate material divided into four parts of 20/30, 14/20, 10/14 and 5/10 mm at three different temperatures (5°C, 20°C and 40°C). Prior to testing, the material must be stored in the oven for at least 4 hours. A standard rammer delivers 56 blows on each of the five layers in the modified Proctor compaction test. The percentage of the material passing through 1.6 mm control sieve is then calculated after aggregate material is subjected to impact loads. It should be noted that the control sieve used in this study is 1.7 mm, similar to that used by Guduru et al. (2022).

RESULTS AND DISCUSSION

Moisture-Density Characteristics

The modified Proctor compaction of VA blends resulted in an optimum moisture content (OMC) and maximum dry densities of 5.5% and 24.1 kN/m^3, respectively. Similarly, the OMC and MDD for the 50-50 RAP material was determined to be 5.0% and 22.1 kN/m^3, respectively. While the OMC and MDD of 50-50 GRAP blends were determined to be 4.43% and 21.4 kN/m^3, respectively. In the case of moisture content, it was found that the presence of RAP reduced the 50-50 RAP blend OMC by 0.5%. In the case of 50-50 GRAP, the reduction was 0.57% compared to 50-50 RAP blends. Thus, the presence of the geosynthetic did not significantly alter the moisture characteristic of the RAP-VA blend. While, the MDD for RAP blends was lower than that of VA. The same behavior was found by Guthrie et al. (2007) and Seferoglu et al. (2018), explained by the presence of bitumen surrounding the RAP aggregates, which inhibits compaction and reduces dry densities of RAP-VA blends. On the other hand, the presence of the geosynthetic in the RAP blends did not significantly influence the MDD characteristics compared to that of 50-50 RAP blends.

Permeability Characteristics

The coefficient of permeability for VA blends were determined to be 0.24 cm/s and 0.234 cm/s from duplicated tests. While, the coefficient of permeability of 50-50 RAP and 50-50 GRAP blends were determined to be 0.598 cm/s and 1.17 cm/s, respectively. This is consistent with moisture-density characteristics results obtained in this study for RAP and GRAP blends. On the other hand, researchers (e.g., Mokwa and Peebles 2008; Gupta et al. 2009) reported that the permeability of RAP blends increased as the percentage of RAP material in the blend increased. While, a contradicting behavior was reported by Maher et al. (1997), MacGregor et al. (1999), and Seferoglu et al. (2018). Overall, the differences among different blends tested in this study may be due to the variations in virgin aggregate characteristics, milled RAP aggregate size and bitumen content. In the case of the presence of paving fabrics in the RAP, the coefficient of permeability was higher due to the higher bitumen content and geosynthetic pieces present in the RAP.

Water absorption and Bitumen content

The water absorption values for VA, 50-50 RAP and 50-50 GRAP blends were respectively determined to be 2.82%, 2.06% and 2.51%. The water absorption value of 50-50 RAP blend was lower than the VA due to the aged binder coated on to the RAP material. On the other hand, the 50-50 GRAP blend was able to absorb more water than 50-50 RAP blend due to the presence of geosynthetic fragments. The bitumen content of RAP and GRAP samples were determined to be 4.92% and 5.87% respectively, by weight of aggregates. Similar results with 4.5% and 5.0% bitumen contents were obtained for RAP and GRAP samples by Gu et al. (2021) from their study. In addition, they reported that the geosynthetic interlayers absorbs substantial amount of tack based on their asphalt retention capacities, hence a higher binder content was determined in GRAP samples compared to that of RAP samples. On the other hand, Tran et al. (2012) reported the binder contents in RAP and GRAP samples tested in their study as 5.88% and 6.37%, respectively. The variations in the bitumen contents of RAP and GRAP samples among different research studies may be due to the tack coat type and the geosynthetic interlayer adopted.

Fragmentation test

The fragmentation values for VA, RAP and GRAP blends tested at different temperatures are presented in Fig. 11. RAP and GRAP blends showed an increase in the fragmentation value with decreasing test temperature. Similar behavior was observed by Guduru et al. (2022), which was attributed to the brittle behavior of bitumen at a lower temperature, i.e. at 5 °C, compared to other temperatures, which caused the finer agglomerated particles separated because of the repeated impact loading. In fact, the VA blends were not affected by temperature in comparison to the RAP blends. An interesting behavior was noticed in GRAP blends which was less affected by repeated impact loading and temperature compared to RAP blends. It is believed that the geosynthetic fragments may have contributed to more energy dissipation and less grain breakage.

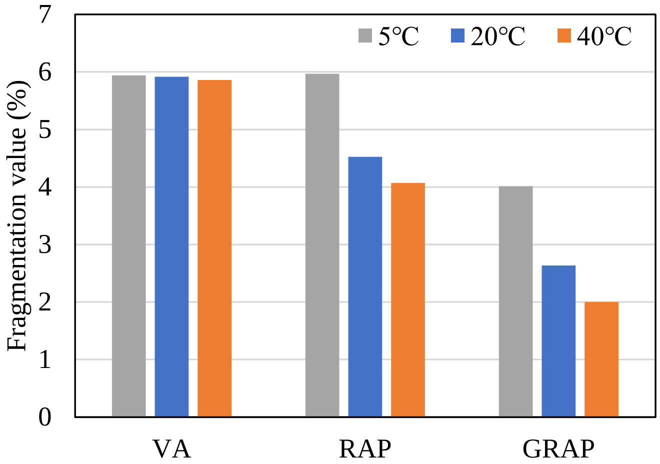

Figure 11. Fragmentation test results on VA, RAP and GRAP blends.

CONCLUSIONS

This study presented characteristics and performance-related parameters and properties of a RAP that contains geosynthetic fibers, referred herein as GRAP, and the suitability of RAP blends with virgin aggregate as roadway base materials. An approach on the milling process of the geosynthetic-reinforced asphaltic layer was presented. The following conclusions were drawn from this investigation:

- The presence of geosynthetic in the asphaltic layers did not affect overall milling process reported in this study.
- The presence of the geosynthetic in the GRAP-VA blends did not significantly influence the moisture-density characteristics compared to that of RAP-VA blends tested in this study.
- Hydraulic permeability of different blends evaluated in this study were on the order of 0.24 cm/s, 0.598 cm/s, and 1.17 cm/s respectively, for VA, 50-50 RAP and 50-50 GRAP blends.
- The presence of geosynthetic fragments in the GRAP-VA blends has significantly influenced the permeability characteristics.
- The water absorption capacity of GRAP samples were higher than of the RAP samples evaluated in this study, due to the presence of geosynthetic fragments in the GRAP sample.
- The binder content of GRAP samples were higher (5.87%) than that of RAP samples (4.92%) evaluated in this study, due to the asphalt retention capacity of geosynthetic fragments in the GRAP sample.
- The fragmentation values of GRAP and RAP samples evaluated in this study, decreased with increasing temperature. In addition, GRAP sample was less affected by repeated

impact loading and temperature compared to that of RAP sample, due to the presence of geosynthetic fragments in the GRAP sample.

Overall, it can be inferred that behavior of RAP blends may differ depending on virgin aggregate characteristics, milled RAP aggregate size and bitumen content, as well as RAP percentage and compaction conditions.

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