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Effect of geosynthetic reinforcement insertion on mechanical properties of hot and cold asphalt mixtures

Géssica Soares Pereira*, Heraldo Nunes Pitanga, Taciano Oliveira da Silva,
Déborah Castro e Almeida, Kamila Bazoni Lunz

Civil Engineering Department, Federal University of Viçosa, Viçosa, Minas Gerais, Brazil

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Abstract

The main objective of this research is to analyze the effect of the insertion of a geogrid reinforcement in the mechanical behavior of the hot mix asphalt (HMA) and the cold mix asphalt (CMA). For this purpose, an experimental program was developed, in which HMA and CMA were designed by the Marshall mix design method and specimens with and without a geogrid were molded. The mechanical properties were investigated through tensile strength (Brazilian test), resilient modulus and Marshall Stability tests. The insertion of the geogrid into the HMA provide an increase in the responses of reinforced specimens for the three analyzed tests, which is not observed in the CMA. The adhesion between the asphalt mixture and the geogrid is observed only in the hot asphalt mixture. Therefore, its mobilization shows to be dependent on the temperature of the asphalt mixture, which alters the viscosity of the asphalt binder. It is assumed that the geogrid reinforcement is mobilized due to the adhesion between this geosynthetic element and the hot asphalt mixture. Additionally, the trapping of the asphalt mixture in the geogrid mesh openings provides the formation of a structural system with higher interlocking, lower susceptibility to deformations and as a consequence greater mechanical strength and stiffness, in comparison to unreinforced systems.

Keywords: Asphalt mixtures; Geogrid; Hot mix asphalt (HMA); Cold mix asphalt (CMA); Interaction mechanisms

1. Introduction

In road engineering, most of the pavement structures have the asphalt layer composed of asphalt mixtures. Two main options of this paving material are hot mix asphalt (HMA) and cold mix asphalt (CMA). As the name implies, HMA is a mixture of aggregates and asphalt cement that requires heating before installation. Hot mix asphalt is more useful for large-scale paving applications because it can resist all types of weather and is the most durable grade of paving asphalt. On the other hand, CMAs are the most basic asphalt types and are much more affordable than hot mix asphalt. As they can be laid in colder temperatures, health risks are reduced because heating of materials is not required for application, and furthermore, they can provide a longer storage time than hot mix asphalt.

According to Slebi-Acevedo et al. [1], scientists and engineers are permanently trying to improve the properties of asphalt mixtures, such as their stability and durability. In this context, this research aims to evaluate the improvement of mechanical properties of HMA and CMA through the insertion of geosynthetics.

Geosynthetics have been widely used in paving engineering, mainly for application in drainage systems and reinforcement of embankments and structural layers of pavements. Kakuda et al. [2] state that the use of geosynthetics as a reinforcement element allows the control and reduction of distress manifestations such as rutting or fatigue cracking, being effective in reducing both permanent and resilient deformation. Correia [3] points out that the presence of these materials in asphalt pavements can lead to significant improvements in the rehabilitation of pavements by increasing their service life and consequently reducing maintenance costs.

In addition, research has shown that the service life of flexible pavements can be extended by the inclusion of geotextiles or geogrids between the existing layer and the new asphalt overlays, due to the ability of the geosynthetic to absorb stresses and therefore minimize the mechanism of reflection cracking [4-13].

Fonseca et al. [14] state that the use of geogrids to reinforce asphalt pavements can increase the fatigue life of the pavement

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* Corresponding author
E-mail addresses: gessicasoares.p@gmail.com (G. S. Pereira); heraldo.pitanga@ufv.br (H. N. Pitanga); taciano.silva@ufv.br (T. O. da Silva); deborah.castro@ufv.br (D. C. Almeida); kamila.lunz@ufv.br (K. B. Lunz).
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because the reinforcing elements prevent the mechanism of reflection cracking. According to Montestruque [15], it prevents the formation of a single reflection crack that monopolizes the dissipation of energy at its end and forces the appearance of many microcracks distributed over the asphalt layer with a scattered propagation pattern, lower growth speeds and lower severity.

The use of geogrids in asphalt mixtures to achieve an improvement in pavement performance is governed by confinement/interlocking and bonding mechanisms [16].

Antunes [17] states that the reinforcement of asphalt layers with geogrid contributes to a greater performance of the pavement, promoting the reduction of deformations and a better absorption of horizontal stresses. Therefore, the reinforcement reduces the shear stresses transferred to the layers in which the geosynthetic is inserted due to the interlocking created between the mesh openings and the aggregates of the asphalt mixture [18]. Without this interlock, the shear strength at the interface decreases excessively due to the presence of the reinforcement and negatively affects the overall strength of the mixture [19].

According to Knonw et al. [20], among the various geosynthetic products, geogrids are believed to improve the confinement under the vehicles' wheel loading. Therefore, they are the best option for achieving an improvement in the structural performance of flexible pavements, mainly providing reinforcement for the pavement structure.

According to several researches [21-25], adhesion is the determining factor for the good performance of the reinforcement in pavement layers. Moreover, according to Montestruque et al. [26], the appearance of premature cracks can be caused by the lack of adherence between an asphalt layer and a geogrid. Kakuda [27] states that asphalt mixtures must constitute a monolithic structure, as the lack of adherence leads to an increase in shear stress at the layer interface.

Bastos [28] states that the anchoring of the geosynthetic in the asphalt layer is given by the adhesion between a geogrid and an asphalt mixture. The researcher also states that there should be no relative displacement between the geogrid and the asphalt concrete for the geogrid to absorb stresses when it is stimulated to deform.

Montestruque et al. [26] say that the eventual relative movement between the asphalt layers and the geogrid prevents the adequate mobilization of the reinforcement and, consequently, the adequate absorption of the stresses to which the system is subjected. Thus, one must ensure the integrity of the whole through a good adhesion between the geosynthetic and the asphalt mixture.

Obando-Ante [29] highlights that the efficiency of geosynthetics as reinforcement of asphalt mixtures is strongly influenced by factors such as the selection of the asphalt binder and its viscosity. Nithin et al. [30] affirm that the temperature used on the installation of the geosynthetic is fundamental to guarantee the adhesion between the asphalt layer and the geogrid. Button and Lytton [31] indicate that the installation of the geosynthetic must be carried out with petroleum asphaltic cement at temperatures between 82ºC and 132ºC, in order to guarantee the adequate viscosity of the binder.

The particularities of hot and cold asphalt mixtures can lead to different influences on the reinforcement mechanisms associated with the insertion of geosynthetics in such mixtures. In this context, this research aims to perform a comparative analysis between the mechanical properties (tensile strength, resilient modulus and Marshall Stability) of HMA and CMA with and without geogrid insertion.

2. Materials and methods

2.1. Materials

The components of the HMA studied are mineral aggregates of gneissic origin (gravel 1, gravel 0 and stone powder) and a conventional petroleum asphaltic cement (CAP 50/70). Regarding to the composition of the CMA, the same mineral aggregates of gneissic origin present in the HMA composition and a conventional cationic asphalt emulsion (RL-1C) were used. The Tables 1, 2, and 3 present the normative procedures for the characterization tests of these materials.

The geogrid analyzed in this research was developed to reinforce the asphalt layers. This geogrid is composed by polymeric filaments produced from high modulus glass fibers and covered with bituminous material. These filaments are adhered to an ultralight non-woven geotextile whose purpose is to assist the geogrid installation process in a real asphalt pavement structure. Then, it does not have any structural function. The technological characteristics of this geogrid (Fig. 1) provided by the manufacturer are shown in Table 4.

2.2. Methods

For the hot asphalt mixture, a granulometric composition was defined according to the Brazilian specification ES 031 [32],

Table 1
Characterization tests of mineral aggregates for composition of HMA and CMA.

Test	Standard
Adhesivity to the asphalt binder	ME 078 [33]
Form index	ME 086 [34]
Sand equivalent test	ME 054 [35]
Los Angeles abrasion	ME 035 [36]
Absorption	ME 081 [37]
Real and apparent specific density	ME 081 [37]
Granulometric analysis	ME 083 [38]
Specific density of fine aggregate	ME 194 [39]

Table 2
Characterization tests for petroleum asphaltic cement (CAP 50/70).

Test	Standard
Viscosity Saybolt-Furol	ME 004 [40]
Flash point	ME 148 [41]
Fire point	ME 148 [41]
Real specific density	ME 009 [42]
Relative density	ME 009 [42]
Solubility in Trichlorethylene	NBR 14855 [43]
Softening point	ME 131 [44]
Penetration	ME 155 [45]

Table 3
Characterization tests for asphalt emulsion (RL-1C).

Test	Standard
Density	ME 193 [46]
Particle charge test	ME 156 [47]
Determination of pH	NBR 6299 [48]
Sieve test	NBR 14393 [49]

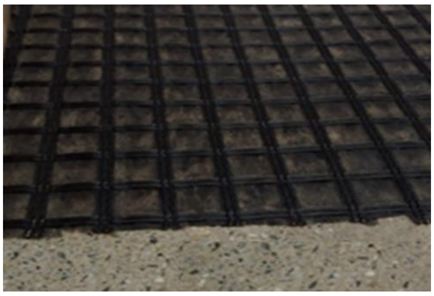

Fig. 1. Geogrid used in the research.

Table 4
Properties of the geogrid analyzed in the research.

Property	Magnitude
Ultimate tensile strength	64.60 kN/m
Elongation at maximum load	2.4%
Strength at 2% strain	56.48 kN/m
Aperture size	30 mm x 30 mm

which is applicable to HMA (Grading Envelope C). Then, the asphalt binder design content of the hot asphalt mixture was defined using the Marshall mix design method, according to the ME 043 standard [50].

For the cold asphalt mixture, a granulometric composition was defined in order to fit the Grading Envelope D of the ES 153 standard [51]. Then, the formulation proposed by Duriez and Arrambide [52] was used to calculate the residual binder content, that is, the amount of effective asphalt present in the asphalt mixture for the composition of mineral aggregates. To determine the moisture content of the aggregate composition, usual values were sought in the technical previous literature [53-56] and the value of 2.5% was selected, since it provides satisfactory results of workability and grain covering.

After choosing the moisture content and defining the initial asphalt emulsion content, a moisture content in relation to the aggregate mass of 4.4% was used for compaction of the asphalt mixtures. This moisture content was determined based on Marshall Stability values presented in the ME 107 standard [57]. The mixture was designed using the Marshall mix design method, according to the ME 043 standard [50], and the asphalt binder design content was then obtained.

After determining the asphalt binder design content for both mixtures, some specimens were molded with the insertion of the geogrid and others without the geogrid. For the molding of specimens with geogrid, the asphalt mixtures were divided and homogenized in two separate containers, each containing 50% of the aggregate fractions and 50% of the asphalt binder content defined in the design process. These halves of asphalt mixtures were used to cast each half of the same specimen.

In the case of HMA mixtures, the sample of the first half of the specimen was homogenized and returned to the oven for two minutes, which is a time interval defined by ME 043 [50] for hot asphalt mixtures. While the first sample was kept in the oven, the second half of the sample was homogenized. Then, this second sample was also taken to the oven for two minutes. During this interval, the first sample was deposited in the mold of the Marshall compactor. After that, two blows (impact type) were applied in order to obtain a leveling and then the geogrid was inserted. After these procedures, the second half of the sample was taken from the oven and placed in the same mold over the geogrid. Then, this Marshall mold was prepared with 75 blows (impact type) on either side.

With regard to the CMA mixtures, the same proceedings were used, except for the steps of heating the mixture. Fig. 2 shows a molded specimen reinforced with geogrid and a demarcation of the position of its reinforcement.

For the analysis of the mechanical properties of reinforced and nonreinforced HMA and CMA specimens, mechanical tests of tensile strength, resilient modulus, and Marshall Stability were performed as per ME 136 [58], ME 135 [59], and ME 043 [50], respectively. Although they do not represent the dynamic loading condition that asphalt layers are typically subjected due to the vehicle traffic in a pavement structure, the static tests of tensile strength and Marshall Stability are justified because they correspond to requirements defined in Brazilian specifications for asphalt mixtures (ES 031 [32] for hot asphalt mix and ES 153 [51] for cold asphalt mix). These specifications prescribe minimum values for such properties that must be met by the respective designed asphalt mixtures. Thus, together with the resilient modulus test (performed under dynamic loading condition), these static tests will be used for comparative purpose.

In the Marshall Stability tests, the specimens were heated to 60°C in an oven and then placed in lower segment of the breaking head. The upper segment of the breaking head of the specimen is placed in position and the complete assembly is placed in position on the testing machine as shown in Fig. 3. The test consists of applying an increasing compressive load on the specimen and the Stability of the mix is defined as the maximum load carried by the compacted specimen.

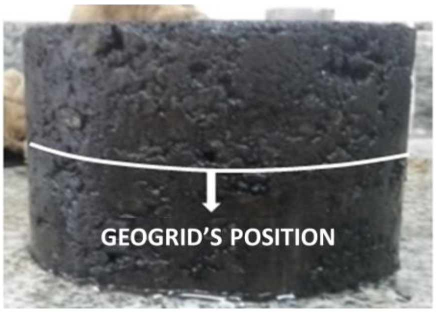

Fig. 2. Illustration of a test asphalt mixture specimen reinforced with geogrid.

Fig. 3. Marshall Stability testing machine.

In the Brazilian diametrical compression test, an indirect determination of the tensile strength of the asphalt mixtures was developed, considering a monotonic compressive loading applied by loading strips to the Marshall size samples (with and without geogrid), as shown in Fig. 4. The application of the diametrically opposed compressive loads generates uniform tensile stresses perpendicular to the vertical diameter of the cylinder.

The tensile strength at failure is calculated using the theory of elasticity and neglecting the effects of multiaxial state of stress. According to the Brazilian standard method for asphalt mixtures, it is assumed that the specimen fails when the uniform tensile stresses generated over the requested diameter is equal to the maximum allowable tensile stress of the sample. So, the indirect tensile strength is the maximum tensile stress applied to the sample during the test.

In order to determine the asphalt mixtures stiffness, resilient modulus tests of Marshall cylinder specimens of HMA and CMA with and without geogrid were performed, at a controlled temperature of 25°C. During the tests, the specimens were subjected to a cyclic axle load on the vertical diametrical plane.

The load applied by the loading strips generates tensile stresses along the vertical diametrical plan. These tensile stresses cause recoverable diametrical strains along the horizontal direction. Diametral and horizontal strains were measured with electromechanical Linear Variable Differential Transformers (LVDTs) (Fig. 5). The value of resilient modulus was calculated as the ratio of applied axle deviator stress and axle recoverable strain.

Fig. 4. Tensile strength testing machine.

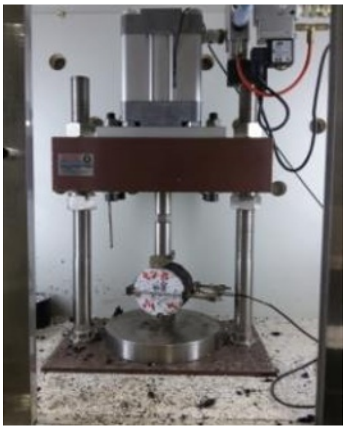

Fig. 5. Resilient modulus testing machine.

3. Results and analysis

3.1. Characterization of mineral aggregates

Table 5 presents the results regarding the characterization of the mineral aggregates used for the HMA and CMA mixtures analyzed in this research. The particle size analysis of mineral aggregates is presented in Fig. 6.

3.2. Asphalt binder characterization

Tables 6 and 7 present the results of the characterization of the petroleum asphaltic cement (CAP 50/70) and the cationic asphalt emulsion (RL – 1C), respectively.

3.3. Grading of design

In this research, designed asphalt mixtures corresponding to two grading envelopes [C specified by ES 031 [32] to HMA and D specified by ES 153 [51] to CMA were used. Fig. 7 presents the

Table 5
Results of the characterization tests of mineral aggregates for HMA and CMA.

Test	Result
Adhesivity to asphalt binder	Satisfactory with the addition of 0.10% doping material
Form index	0.68
Sand equivalent test- Stone powder	59%
Los Angeles abrasion	45%
Absorption – Gravel 0	1.14%
Absorption - Gravel 1	1.14%
Real specific density - Gravel 0	2.796 g/cm³
Real specific density - Gravel 1	2.817 g/cm³
Apparent specific density - Gravel 0	2.705 g/cm³
Apparent specific density - Gravel 1	2.705 g/cm³
Real specific density - Stone powder	2.825 g/cm³

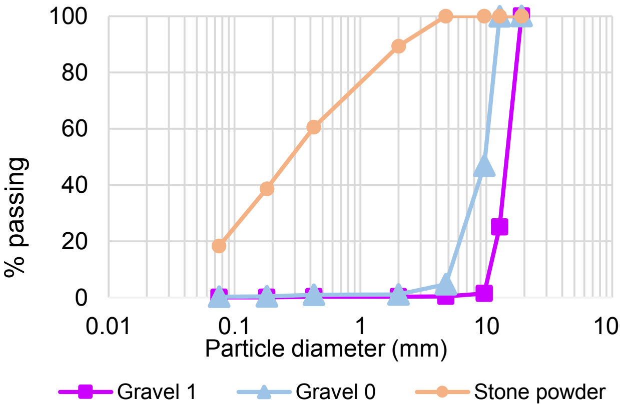

Fig. 6. Particle size analysis of mineral aggregates to HMA and CMA.

grading of design used in this research for the two grading envelopes analyzed. For these envelopes, the design gradation curves were determined in accordance with the limits imposed by the mentioned service specification.

Table 6
Results of the characterization tests of the petroleum asphaltic cement (CAP 50/70).

Test	Result
Viscosity Saybolt-Furol	135°C – 172 seconds 150°C – 64 seconds
Flash point	343°C
Fire point	365°C
Real specific density	1.010 g/cm³
Relative density	1.006
Solubility in Trichlorethylene	100%
Softening point	51°C
Penetration	57 dmm

Table 7
Results of the characterization tests of the cationic asphalt emulsion (RL-1C).

Test	Result
Density	1.030 g/cm³
Determination of pH	3.09
Particle charge test	Positive charge
Sieve test	0.01%

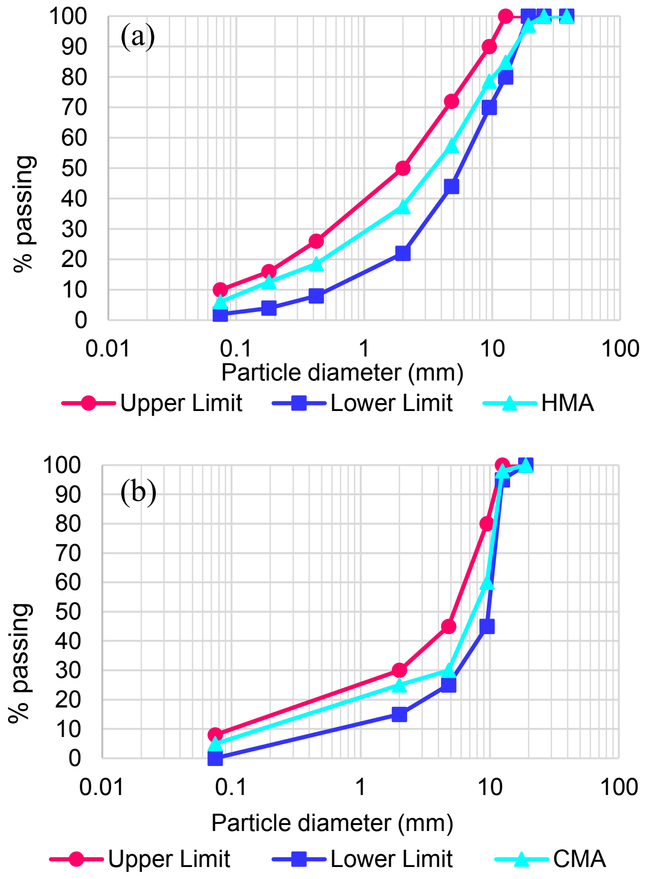

Fig. 7. Design gradation curves for both grading envelopes of this research: (a) HMA and (b) CMA.

3.4. Design asphalt mixtures

Table 8 presents the results of the volumetric parameters of the HMA and CMA with their asphalt binder design contents defined by the Marshall mix design method. These values of asphalt binder design contents were determined so that the corresponding volumetric parameters are within the range imposed by the service specifications ES 031 [32] and ES 153 [51] for the HMA and CMA, respectively.

3.5. Mechanical tests

Figs. 8, 9, and 10 present the results of tensile strength, resilient modulus and Marshall Stability tests performed on the test specimens of HMA and CMA design asphalt mixtures with and without geogrid reinforcement.

Table 8
Volumetric parameters for the HMA and CMA design asphalt mixtures.

Asphalt mixture	HMA	CMA
Grading envelope	C	D
Asphalt binder design content (%)	4.70	7.00
Voids Content (%)	4.19	11.9
Voids filled with bitumen (%)	76.10	44.81

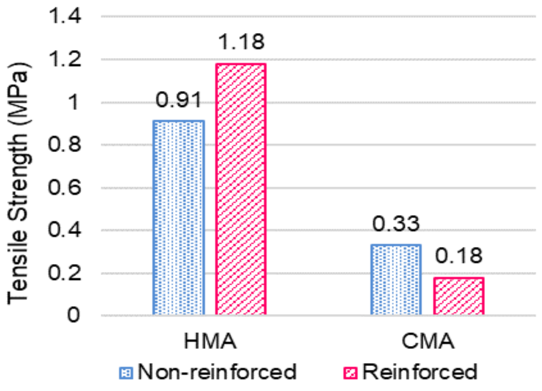

Fig. 8. Results of tensile strength for the design asphalt mixtures investigated.

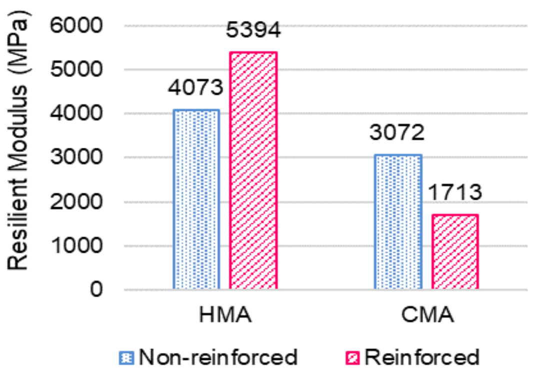

Fig. 9. Results of resilient modulus for the design asphalt mixtures investigated.

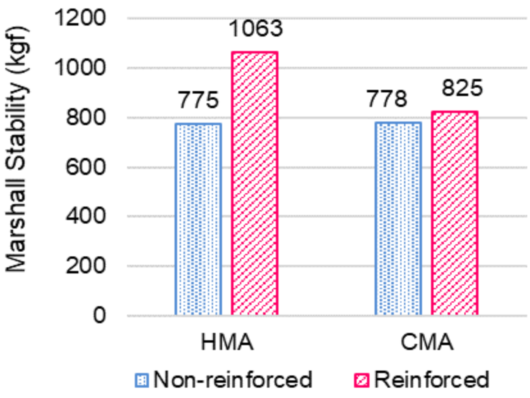

Fig. 10. Results of Marshall Stability for the design asphalt mixtures investigated.

These results showed that the geogrid insertion provided an increase in the mechanical properties of conventional HMA, which was not observed when geogrid was inserted into the CMA. Specimens of the two types of reinforced mixtures were exhumed. An investigation of these specimens suggested that the difference in the mechanical responses is associated with the evidence of adherence of the geogrid to the HMA (Fig. 11), which was not verified in the CMA (Fig. 12).

Regarding the interaction of the geogrid with the HMA, an inspection of divided reinforced specimens indicated (Fig. 11) that the geogrid meshes were totally connected to the hot asphalt mixture. Therefore, they constituted a monolithic system with a high degree of integrity.

Fig. 11. Geogrid adhered to the hot asphalt mixture (HMA).

Fig. 12. Geogrid not adhered to the cold asphalt mixture (CMA).

The geogrid used in this research has filaments covered with bituminous material. Thus, for the compaction temperature, the asphalt present in the geogrid and in the hot asphalt mixture is in a state of consistency that promotes adequate adhesion between the geogrid and the hot asphalt mixture. This adhesion was preserved after the specimens have cooled down to room temperature.

Regarding the interaction of the geogrid with the CMA, no adherence between these elements was observed when the reinforced specimens were divided (Fig. 12). The lack of adhesion between the filaments of the geogrid mesh and the asphalt mixture resulted in the detachment of the geogrid from the cold asphalt mixture. Thus, the impossibility of mobilizing the adhesion prevented the geogrid and the cold asphalt mixture from forming a monolithic system, thus restricting the geogrid's ability to act as a reinforcement of the asphalt mixture.

It is important that the aforementioned experimental findings and corresponding interaction mechanisms described support the mechanical responses obtained by each of the systems investigated, according to the particularities of the tests contemplated in the experimental program of this research.

Since in the tensile strength test the specimen breaks due to tensile stresses along its vertical diametrical plane, it is possible to infer that the adhered geogrid deformed in the geogrid-asphalt mixture contact zone, promoted a redistribution of internal stresses and absorbed part of the tensile stresses at the central region of the specimen. As the geogrid and the hot mix asphalt form a monolithic system, the reinforcing effect is transmitted through the system, increasing the internal tensile strength in the vertical diametrical plane, in relation to the unreinforced specimens.

In the specimen of CMA, adherence between the reinforcement element and the cold asphalt mixture was not verified. It is assumed that the geogrid does not satisfactorily absorb the tensile stresses in the central region of the specimen. Consequently, it does not transmit the reinforcing effect to the CMA mixture. In addition, the lack of adherence between the geogrid and the compacted asphalt mixture allowed a relative displacement between them. It compromised the integrity of the reinforced specimen and created a physical discontinuity zone within the system, which reduced the tensile strength.

In terms of reinforcement, the general behavior observed in the specimens subjected to the resilient modulus (RM) tests was very similar to that observed in the tensile strength (TS) tests. In the same way of the TS tests, the increments of RM response observed in the reinforced HMA is associated with the stress absorption by the geogrid, which results from the adhesion between the hot asphalt mixture and the geogrid meshes. This adherence allows the mobilization of the geogrid under the action of the internal stresses generated by the dynamic loading that characterizes this test, resulting in an increase in the resilient stiffness of the HMA reinforced. This behavior was not observed in CMA specimens due to the lack of adherence between the geogrid and the cold asphalt mixture.

Knowing that the RM test occur through the application of repeated loading and that the horizontal deformations resulting from this test are analyzed, it is inferred that the geogrid adhered to the hot mix asphalt absorbs the tensile stresses when deforming at each loading cycle and consequently reduces the recoverable horizontal displacements. Thus, an increase in the elastic stiffness of the geogrid-HMA system was observed.

In the reinforced cold asphalt mixtures, because a lack of adherence, a formation of a monolithic system was not observed. This condition allowed a relative displacement of the geogrid, which restricts their confinement/interlocking mechanism and implies in a not satisfactory solicitation of the reinforcement element. In addition, the non-adherent geogrid constitutes an area of physical discontinuity within the specimen that impairs its performance during the application of the cyclic loading and generates lower RM tests results.

In Marshall Stability tests, the force applied during the tests increases until excessive displacement or failure of the asphalt mixture occurs. Then, the results presented in Fig. 10 indicate that one of the effects of the presence of the geogrid is to provide greater interlocking and confinement to the system. In this way, the system formed by geogrid and asphalt mixture is less susceptible to structural collapse and presents highest values of Marshall Stability.

In reinforced HMA, the combination of the adhesion and the trapping of the asphalt mixture in the geogrid mesh openings provides the formation of a structural system with higher interlocking and greater Stability, consequently. Regarding to the CMA, as the geogrid is loose in the asphalt mixture and dislocates during the application of the loading, an unsatisfactory condition is provided for the development of the geogrid reinforcement mechanisms, implying in a restricted potential for increasing Stability by the geogrid.

This research deals with specific types of asphalt mixtures (cold and hot), geosynthetic reinforcement (geogrid) and static (Marshall Stability and tensile strength) and dynamic (resilient modulus) tests. Considering these particularities, the results of the experimental program corroborate with the previous knowledge that adherence is the primary mechanism necessary to mobilize the geogrid reinforcing ability, which is responsible for improving the mechanical properties of asphalt mixtures. As a consequence of the experimental findings presented in this paper, future research must be carried out in order to propose and evaluate complementary procedures focused on solving the problem of lack of adherence and, consequently, the lack of reinforcement in cold asphalt mixtures reinforced by geogrids, with a view to make this technique feasible as evidenced for the hot asphalt.

4. Conclusions

Based on the results and considering the particularities of this research, it was possible to verify that:

1. The geogrid showed satisfactory adherence to the hot mix asphalt and did not show any adherence to the cold mix asphalt.
2. The efficiency of transmission of the reinforcing effect, which is mobilized by the actuation of the geogrid, has been shown to be associated with the geogrid-asphalt mixture adherence. This adherence was achieved only in the hot asphalt mixture. Therefore, it was dependent on the compaction temperature of the asphalt mixture.
3. The adhesion between the geogrid and the asphalt mixtures was shown to be associated with the temperature of the mixture. It is due to the influence of the geogrid on the viscosity of the asphalt binder of the mixture and the geogrid, which allows the adhesion between them.

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