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Possibility of use of granite fines in asphalt pavements

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Abstract

The deposits of minerals in Lithuania are quite limited, also the mineral aggregates there are only low or average strength, such as sand, gravel and dolomite. High strength materials (granite) are imported from the east and north in narrow fraction and later on are processed into desirable fraction or mix. The fractionation process of large granite aggregates leaves huge amount of secondary product – granite fines. So the problem of appliance or utilization of this filler emerges. One of the possibilities could be the use of granite fines in asphalt pavements. In this study, a laboratory investigation was conducted on the physical and mechanical properties of asphalt mix reliant of mineral filler type. The asphalt mix physical and mechanical properties were carried out using maximum density of asphalt mix test, bulk density of bituminous specimens test, void characteristic of bituminous specimens test, Marshall test, indirect tensile strength test, wheel tracking test. Also, according to the results of laboratory testing, the possible ways and tendencies of use of granite fines in asphalt pavements are projected.

Keywords: Mineral filler; granite fines; Marshall test; indirect tensile strength test; wheel tracking test.

Nomenclature

CBR	California bearing ratio
G*	Complex modulus
sinδ	Low phase angle

1. Introduction

The deposits of minerals in Lithuania are quite limited, also the mineral aggregates there are only low or average strength, such as sand, gravel and dolomite. In Lithuania found about 950 mln. m^3 granite, but it is not mining due to occurring depth (200–300 m) and Dzukija National Park neighbourhood. Chrushed granite aggregates are imported from neighbouring countries such Ukraine, Sweden, Poland, Norway, Finland, etc. [1], [2]. Chrushed granite aggregates are imported in narrow large fractions – 20/40 mm, 40/70 mm. Homegrown manufacturing companies processing imported granite material into wide and narrow fractions. The fractionation process of large granite aggregates leaves huge amount of secondary product – granite fines, which occupies a lot of territory and this problem is relevant in other countries [3].

Sridharan *et al.* (2005) studied the effect of quarry dust in highway construction that CBR and angle of shearing resistance values are steadily increased with increase the percentage of quarry dust [4]. Soosan *et al.* (2001) identified that crusher dust exhibits high shear strength and is beneficial for its use as a geotechnical material [5]. Choundhary and Chandra (2008) carried out that the addition of marble and granite dusts to asphalt concrete can produce properties comparable to the conventional asphalt concrete mixes with stone dust as filler. They found that these fillers can be used up to 7% in asphalt concrete mixes, but it is suggested to use them in the range of 4.0 to 5.5% initially to observe their performance in field. Rheological tests conducted on filler-asphalt mastic showed highest value of (G*/sinδ) of granite dust indicating high resistance to rutting of this filler [6]. Ribeiro *et al.* (2008) found that granite and basalt mineral filler physical properties are similar, whereas asphalt mix with granite and basalt mineral filler mechanical resistance meets with requirements [7]. Binici *et al.* (2008) found that the marble and granite waste aggregates can be used to improve the mechanical properties, workability and chemical resistance of the conventional concrete mixture. Also, it makes sense from

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the economic and environmental viewpoints to use these materials as aggregates in the production of more durable concrete mixtures [8].

In foreign countries granite and other mineral filler as secondary product use is applicable. The scientists give much attention to the rationalization of the use of this filler.

2. Influence of components on asphalt mix properties

Asphalt concrete is composed primarily of aggregate and binder. Aggregate typically makes up about 95% of an asphalt mixture by weight, whereas asphalt binder makes up the remaining 5%. By volume, a typical asphalt mixture is about 85% aggregate, 10% binder, and 5% air voids. Small amounts of additives and admixtures are added to many asphalt mixtures to enhance their performance or workability [9].

Most specific asphalt mix properties are stiffness, elasticity, resistance to fatigue and low temperature cracking. These properties varies in wide limits depend on ambient temperature, loading rate and total loads quantity.

Asphalt structure is described by the grading of aggregate (mixture of mineral materials), the properties of mineral materials, the structure and properties of binding material and also by the interrelation of binder and mineral materials.

The main condition in order to ensure max asphalt strength is a dense structure of aggregate (mixture of mineral materials) which is reached by properly selecting the grading and the optimum binder content for the specific mineral composition of the mixture under existing mixing and compaction conditions [10–12].

Bitumen is a material characterized by a time of loading and temperature dependence of the mechanical response to loading [13]. In hot climatic conditions or under slow moving trucks, asphalt behaves like a viscous liquid and only aggregates are the contributing element of hot mix asphalt that bear the traffic loads. At micro level, the contiguous layers of molecules seem sliding pass each other. Whereas in cold climatic conditions or under fast moving trucks (rapidly applied loads), asphalt behaves like an elastic solid and deforms when loaded, but returns to its original shape when unloaded. If it is stressed beyond its strength, it may rupture [14].

One of the most important characteristics of asphalt binders that must be addressed in test methods and specifications is that their precise properties almost always depend on their temperature. Asphalt binders tend to be very stiff and brittle at low temperatures, thick fluids at high temperatures, and leathery/rubbery semi-solids at intermediate temperatures. Such extreme changes in properties can cause performance problems in pavements. At high temperatures, a pavement with a binder that is too soft will be prone to rutting and shoving. On the other hand, a pavement that contains a binder that is too stiff at low temperatures will be prone to low-temperature cracking [9].

Mineral filler is the most important structure formation component of asphalt mixture with the largest surface area – the area of up to 90–95% of the asphalt mixture constituent minerals of the total surface area. It was found that optimal combination of binder and mineral filler ratio produce the highest asphalt mix strength. Mineral filler reduction helps to increase resistance to cracking, but reduces resistance to displacement [15], [16]. Mineral filler must have sufficient shear strength to sustain repeated loads. When aggregates are overloaded shear plain expands and aggregate particles losses sufficient adhesion and are cut off or forced out to pavement surface. Aggregate shear strength is particularly important characteristic affecting rutting resistance [17].

Crushed stone particles in asphalt mixture ensure proper bonding, a strong carcass of asphalt mixture and determine the strength of asphalt mixture. The amount of crushed stone in asphalt mixture has an important influence on mixture properties. When the amount of crushed stone in asphalt is small the material gains binding properties. With the increasing amount of crushed stone the connections are formed between structural elements, a carcass is formed, friction between the particles increases. This increases asphalt plasticity as well as the service life of asphalt pavement [18], [19].

Air voids have a significant effect on the resistance of asphalt mixtures to different distresses including rutting, fatigue cracking, moisture damage and low temperature cracking. The distribution of air voids also effect the presence and movement of water in asphalt mixtures. Water gets into asphalt pavements by infiltration of surface water, capillary rise of subsurface water, and diffusion of moisture vapor. The presence of the water in asphalt mixtures has detrimental effects on the pavement structure. It weakens the adhesive bond between the aggregates and binders and the cohesive bond within the binder itself, leading to the disintegration of the asphalt mixture and ultimately failure of the pavement structure [20].

Pavement engineers have worked for many years to relate specific aggregate properties to asphalt mixture performance. Rutting, raveling, fatigue cracking, skid resistance, and moisture resistance have all been related to aggregate properties. It is essential that engineers responsible for asphalt mixture design thoroughly understand aggregate properties, how they relate to asphalt pavement performance, and how aggregate properties are specified and controlled as part of the mix design process.

3. Experimental research

3.1. Object and methods of research

Laboratory testing of granite fines use for the production of road construction materials was carried out at Road Research Laboratory of Vilnius Gediminas Technical University Environmental Engineering Faculty Road Research institute.

Physical and mechanical properties of granite fines were determined from the 10 samples which were taken in 10 different locations from the stockpiles of granite processing plant. Physical and mechanical properties of granite fines were carried out by particle size distribution and particle density determination.

In order to evaluate the same type of asphalt mix, produced with different mineral filler, physical and mechanical properties dependence on the mineral filler, an experimental study were chosen two types of asphalt concrete mixes – AC 11 VS and AC 16 AS, which involve activated limestone and non-activated granite fines. Each type of asphalt mix was mixed with 2 identical gradations and bitumen content with different mineral filler. These asphalt mixes were manufactured with 50/70 bitumen. It was used a chemical additives to improve adhesion of mineral aggregates and bitumen. Later was mixed additional 3 identical gradations asphalt mixes AC 11 VS with activated limestone, non-activated limestone and granite fines. All 3 types fillers gradations were equalized by sieved out through the set of sieves (0.063 mm, 0.125 mm and 2.0 mm) which is regulated by TRA MIN 07. These asphalt mixes were manufactured with PMB 45/80-55 bitumen. All asphalt mixes were mixed according to the standard LST EN 12697-35+A1:2007.

The research scheme of granite fines suitability for asphalt mixes manufacturing is shown in the Figure 1.

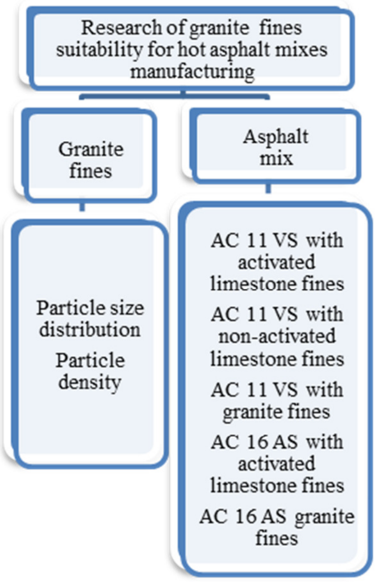


Fig. 1. The research scheme of granite fines suitability for asphalt mix manufacturing

To determine physical and mechanical properties of granite fines and hot asphalt mixes with activated, non-activated limestone fines and granite fines, were carried out these laboratory tests:

- Determination of particle size distribution by LST EN 933-10:2009;
- Determination of the particle density of filler by LST EN 1097-7:2008;
- Determination of the maximum density of asphalt mix by LST EN 12697-5+:2010;
- Determination of bulk density of bituminous specimens by LST EN 12697-6+A1:2007;
- Determination of void characteristics of bituminous specimens by LST EN 12697-8:2006;
- Marshal test (on 60ºC) by LST EN 12697-34+A1:2007;
- Determination of the indirect tensile strength of bituminous specimens by LST EN 12697-23:2003;
- Wheel tracking test by LST EN 12697-22+A1:2007.

3.2. Results of the granite fines testing

Determination of the particle size distribution shown that all 10 samples grading are not comply with the requirements for added filler given in TRA MIN 07 Table 22 because passing through the 0.125 mm sieve is outside the 85–100 % limits and passing through the 0.063 mm sieve is outside the 70–100 % limits (Figure 2).

Determination of the particle density of filler shown that all 10 samples particle density are not comply with the requirements for added filler given in TRA MIN 07 – ≤ 0.2 Mg/m^3. The highest particle density determined in sample No. 5 is 2.88 Mg/m^3. The lowest particle density determined in sample No. 4 is 2.72 Mg/m^3. The average value of all 10 samples particle density is 2.77 Mg/m^3. The results of the particle density test are represented in the Figure 3.

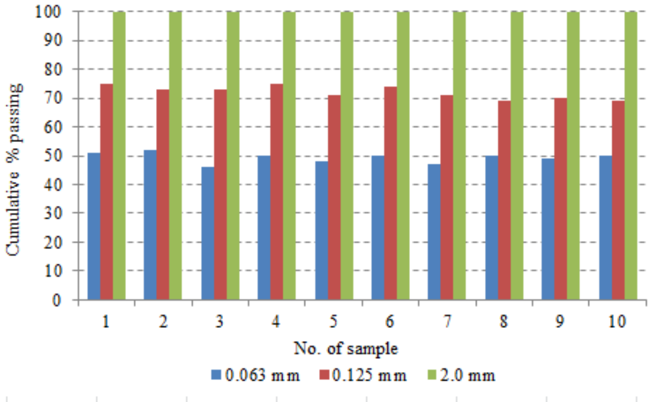


Fig. 2. The results of the particle distribution test of granite fines

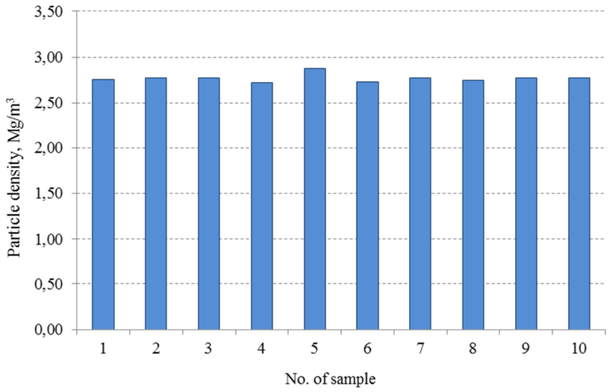
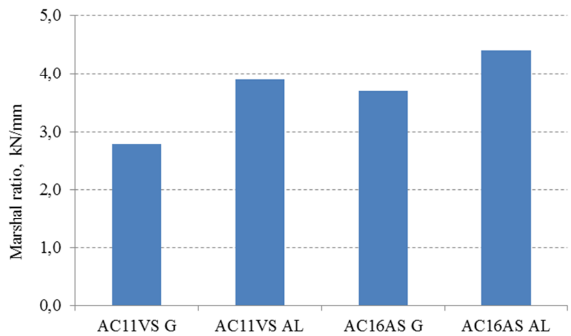


Fig. 3. The results of the particle density test of granite fines

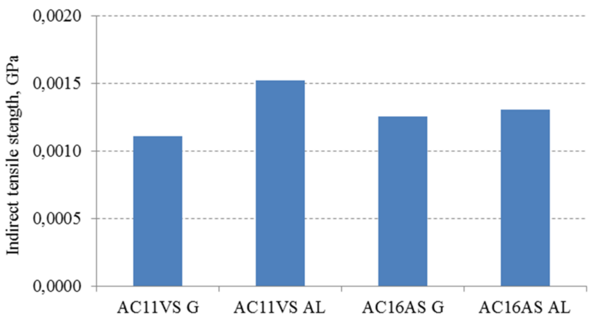
3.3. Results of the granite fines use for asphalt mixes manufacturing

Marshall stability and flow test was carried out by testing 4 samples of each asphalt mix made in laboratory. The average of 4 samples values are used for the analysis of Marshall ratio results. Test shown that Marshall ratio of the asphalt concrete AC 11 VS with granite fines (AC11VS G) is 1.1 kN/mm less than the asphalt concrete AC 11 VS with activated limestone fines (AS11VS AL), whereas Marshall ratio of the asphalt concrete AC 16 AS with granite fines (AC16AS G) is 0.7 kN/mm less than the asphalt concrete AC 16 AS with activated limestone fines (AC16AS AL).

Indirect tensile strength test was carried out by testing 3 samples of each asphalt mix made in laboratory. The average of 3 samples values are used for the analysis of indirect tensile strength test results. Test shown that the average of the indirect tensile strength of the asphalt concrete AC 11 VS with granite fines (AC11VS G) is 0.000413 GPa less than asphalt concrete AC 11 VS with activated limestone fines (AC11VS AL), whereas the average of indirect tensile strength of asphalt concrete AC 16 AS with granite fines (AC16AS G) is 0.000044 GPa less than asphalt concrete AC 16 AS with activated limestone fines (AC16AS AL). According to results of indirect tensile strength test it could be indicated that cohesion of asphalt concrete AC 11 VS and AC 16 AS with granite fines is inferior than asphalt concrete AC 11 VS and AC 16 AS with activated limestone fines. The results of the Marshall test and indirect tensile strength test are presented in the Figure 4.



a) The results of the Marshall test

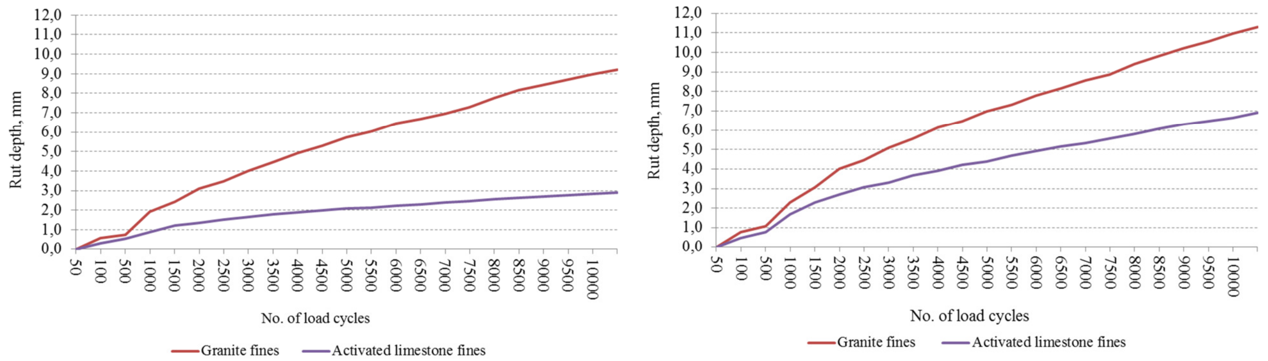


b) The results of the indirect tensile strength test

Fig. 4. The results of the Marshall test (a) and indirect tensile strength test (b) of asphalt concrete AC 11 VS and AC 16 AS with granite fines (G) and activated limestone fines (AL)

Rut depth determination test was carried out by testing 2 samples of each asphalt mix made in laboratory. The average of 2 samples values are used for the analysis of rut depth test results. The average of rut depth after 10 000 load cycles of asphalt concrete AC 11 VS with granite fines is 9.21 mm, whereas the average of rut depth after 10 000 load cycles of asphalt concrete AC 11 VS with activated limestone fines is 2.91 mm. So, the rut depth determination test showed, that asphalt concrete AC 11 VS with granite fines resistance to rutting is significantly inferior than asphalt concrete AC 11 VS with activated limestone fines.

The average of rut depth after 10 000 load cycles of hot asphalt mix AC 16 AS with granite fines is 11.3 mm, whereas the average of rut depth after 10 000 load cycles of asphalt concrete AC 16 AS with activated limestone fines is 6.09 mm. Therefore, the rut depth determination test showed that asphalt concrete AC 16 AS with granite fines resistance to rutting is significantly inferior than asphalt concrete AC 16 AS with activated limestone fines. The results of rut depth test are presented in the Figure 5.



a) Asphalt concrete AC 11 VS   b) Asphalt conrete AC 16 AS

Fig. 5. The results of the wheel tracking test of asphalt concrete AC 11 VS (a) and AC 16 AS (b) with granite fines and activated limestone fines

Air voids content determination test was carried out by testing 3 samples of each asphalt mix made in laboratory. The average of 3 samples values are used for the analysis of air voids content determination test results. Test shown (Fig. 6) that both asphalt concrete AC 11 VS samples (AC11VS G and AC11VS AL) air voids content rate is the equal (0.8%) and satisfies the limits, which is described in ĮT ASFALTAS 08 Clause 72. This limit is 1.5% of required 2.0–4.0% for surface layers mixes, which is represented in TRA ASFALTAS 08 Table 6. The asphalt concrete AC 16 AS with granite fines (AC16AS G) void content rate is 1.9% less than AC 16 AS with activated limestone fines (AC16AS AL). However, it satisfies the limit, which is 1.5% of required 2.0 – 4.0% limit for binder layer mixes. The requirements are described in TRA ASFALTAS 08 Table 6.

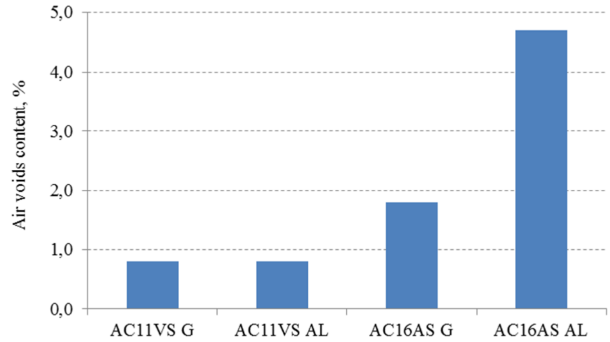
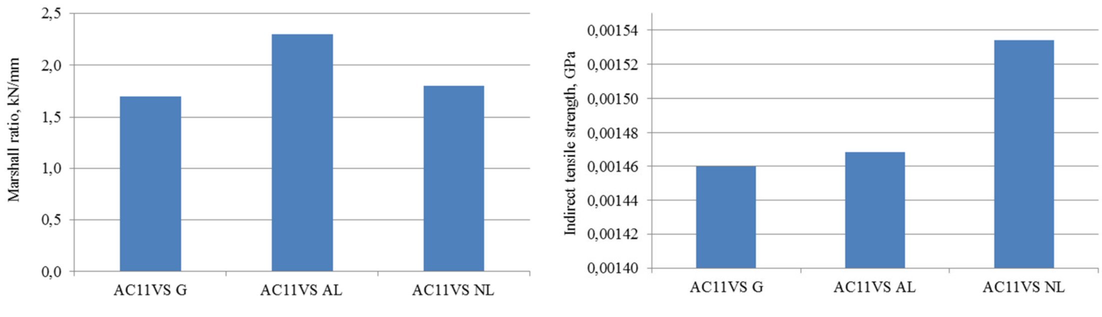


Fig. 6. The results of the void characteristics of asphalt concrete AC 11 VS and AC 16 AS with granite fines and activated limestone fines

Marshall stability and flow test of asphalt concrete AC 11 VS with identical grading of mineral filler shown that asphalt concrete AC 11 VS with granite fines (AC11VS G) Marshall ratio is 0.6 kN/mm less than asphalt concrete AC 11 VS with activated limestone fines (AC11VS AL) and only 0.1 kN/mm less than asphalt concrete AC 11 VS with non-activated limestone fines (AC11VS NL).

Indirect tensile strenght test shown that the asphalt concrete AC 11 VS with granite fines AC11VS G) average indirect tensile strenght is 0.000 009 GPa less than asphalt concrete AC 11 VS with activated limestone (AC11VS AL) and 0.000 074 GPa less than asphalt concrete AC 11 VS with non-activated limestone fines (AC11VS NL). In accordance with this results, we can propose that the asphalt concrete AC 11 VS with granite fines cohesion is inferior than the asphalt concrete AC 11 VS with activated or non-activated limestone fines. The results of the Marshall test and indirect tensile strenght test results are presented in the Figure 7.



a) The result of the Marshall test   b) The results of the indirect tensile strenght test

Fig. 7. The results of the Marshall test (a) and indirect tensile strength test (b) of asphalt concrete AC 11 VS with granite fines, activated and non-activated limestone fines

Air voids content determination test (Fig. 8) shown that the asphalt concrete AC 11 VS with granite fines (AC11VS G) void content rate is 0.2% less than asphalt concrete AC 11 VS with activated limestone fines (AC11VS AL) and 0.1% higher than asphalt concrete AC 11 VS with non-activated limestone fines (AC11VS NL). All 3 samples satisfies the limits of void content rate requirements, which is described in ĮT ASFALTAS 08 Clause 72. This limit is 1.5% of required 2.0–4.0%, which is represented TRA ASFALTAS 08 in Table 6.

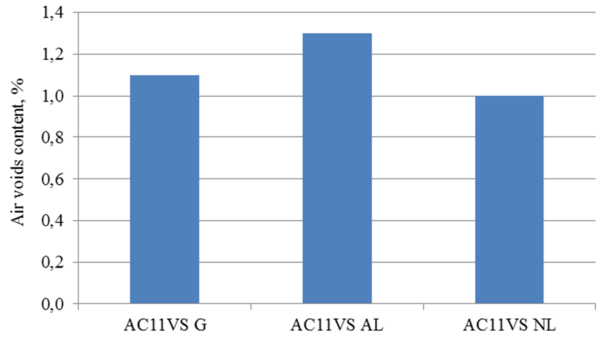


Fig. 8. The results of the voids characteristics of hot asphalt mix AC 11 VS with granite fines, activated and non-activated limestone fines

The equipment and infrastructure of Civil Engineering Research Centre Road Technologies Laboratory of Vilnius Gediminas Technical University were employed for part of the tests investigation.

4. Conclusions

1. The physical properties of granite fines aren't complying with requirements of grading and particle density:
    - Passing through the 0.125 mm sieve is outside the 85–100% limits and passing through the 0.063 mm sieve is outside the 70–100% limits.
    - The average value of all 10 samples particle density is 2.77 Mg/m^3 while requirement is ≤ 0.2 Mg/m^3.
2. Asphalt concrete mixtures with granite fines showed inferior results than asphalt concrete with activated limestone fine by these characteristics:
    - Air voids content rate (AC 11 VS – 0%; AC 16 AS – 2.9%).
    - Rutting resistance (AC 11 VS – 3.16 times; AC 16 AS – 1.86 times).
    - Marshall ratio (AC 11 VS – 39.0%; AC 16 AS – 18.9%).
    - Indirect tensile strength (AC 11 VS – 37.2%; AC 16 AS – 3.5%).
3. While comparing mechanical properties between mixtures with identical granulometric composition, the asphalt concrete AC 11 VS with granite fines showed inferior results than asphalt concrete AC 11 VS with activated and non-activated limestone fines by these characteristics:
    - Marshall ratio (accordingly 26.0% and 5.6%);
    - Indirect tensile strength (accordingly 0.6% and 4.8%).
4. Rut depth determination test showed that mineral filler type preference influence asphalt concrete AC 11 VS than asphalt conrete AC 16 AS, because difference between asphalt concrete AC 11 VS with granite fines and activated limestone fines results is 3.16 times, whereas in asphalt conrete AC 16 AS – 1.86 times.
5. The hot asphalt mixtures with granite fines don't ensure the abilities to reach the same mechanical properties as the hot asphalt mixtures with activated or non-activated limestone fines. For this reason, hot asphalt mixtures with granite fines could be used for binder, base and also for wearing-binder layer asphalt mixtures manufacturing, theretofore additional validation tests should be done.

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