The influence of characteristics of aggregates on performance of asphalt mixtures

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Abstract. Under the current conditions of road traffic growth, importance should be given to the use of construction products whose technical characteristics have to be tested and to comply with the regulations in force. In our country at present there is the European standard EN 13043:2003 regarding the conditions that natural and artificial aggregates must meet in order to be used in asphalt mixtures. As is well known, these conditions are presented in the form of categories of values to be set by the designer to result in an asphalt mix with certain characteristics. However, this standard does not contain a national annex with specifications on the aggregate categories depending on the type of asphalt mix correlated with the technical class / road / street technical category. The majority of beneficiaries that use aggregates in the production of asphalt mixtures have problems on the national market because there is no correlation between this standard and the national provisions in force, namely the AND 605/2016 (version in force on this date). This paper analyzes the conditions that the natural aggregates for the bituminous mixtures must have and correlates the performance of the aggregates with the performance of the asphalt mix.

1. Introduction
The natural aggregates used in asphalt mixtures can either be quarry aggregates or aggregates from riverbeds.

In our country, the provisions of the European Standard SR EN 13043: 2003 / AC: 2004 are applied, which stipulate the conditions that the aggregates must fulfil to be able to be used in asphalt mix recipes. The technical characteristics of the aggregates are geometric, physical-mechanical and chemical characteristics and, depending on the use, the origin of the aggregate as well as the aggregate categories will influence the performance of the asphalt mixtures.

In the European Union and in our country, there are regulations that establish the conditions for construction materials to be used in asphalt mixtures. Thus, the study of the technical characteristics of the aggregates and the imposing of technical conditions is imperative for the development of roads that provide safety and durability.

The natural aggregates have a polyhedral form and are obtained by crushing, granulating and sorting in grain classes. When designing asphalt mix, it is recommended to use hard rocks, usually magmatic, which are chemically basic or semi-basic. As is known, the use of acidic rocks requires the use of special additives to increase the adhesion between the aggregate and the bitumen.
2. Physical-mechanical characteristics of aggregates

The conditions to be fulfilled by natural aggregates refer both to the granularity class, the fine grain content and the quality of the fine parts as well as the shape of aggregates.

Regarding the geometrical characteristics, the establishment of the granularity class is very important in the design of the asphalt mix recipe and although the European Standard SR EN 13043: 2003/AC: 2004 provides categories of grain contents and limits outside the grain size class that go up to 35% (GC 85/35), in our country it is not recommended to use aggregates with more than 10% (GC 90/10) granule content outside the granularity class. Given that both the size of the aggregates and the shape change over time, it is necessary to impose more restrictive conditions on the granule content outside the granularity class which will influence the technical characteristics of the asphalt mix.

As is known, several steps are required to determine the composition of an asphalt mixture, comprising in the first part a check of the characteristics of the component materials, namely the aggregates, the bitumen and the filler; followed by a determination of the percentage of participation of each component in the complete asphalt mixture, and finally the optimal dosage is validated based on the initial type tests. [1],[4],[5].

The properties of asphalt mixtures are influenced by physical-mechanical and quality characteristics of the component materials.

A study was carried out in the INCERTRANS laboratory regarding the preparation of an asphalt mixture BA 16 rule 70/100 pen with 5.9 % of bitumen. Three recipes of asphalt mixes were developed using quarry aggregates: dolomite limestone, andesites and aggregates from riverbeds. A comparison of the results was performed to study how the performance of the mixture is influenced by using aggregates, quarry andesitic aggregates and riverbeds aggregates.

The physical and mechanical characteristics of the aggregates used are shown in Tables 1, 2, 3 and 4. The study investigated the affinity between the bitumen used for the preparation of asphalt mixtures, type 70/100 pen and the three types of aggregates proposed. In this study, the qualitative method according to SR EN 12697-11:2012 was used to determine the degree of bitumen coverage. The results obtained are shown in Table 4. Because the results obtained gave values over 80%, it is not necessary to additive the 70/100 pen bitumen to increase the affinity between aggregates and bitumen.

Table 1. Physical-mechanical properties of aggregates size: 0-4 mm [Technical documentation, Incertrans S.A.] [2]

| Parameter determined | Test method | U.M | Average value sort: 0-4 mm | Technical conditions according to AND 605/2016 | Technical conditions according to SR EN 13043 |
|----------------------|-------------|-----|---------------------------|-----------------------------------------------|-----------------------------------------------|
| Granulosity Passes on the sieve of: | SR EN 933-1 | % | dolomite-limestone | Andezit | Crushed sand | Natural sand | | |
| 6.3 mm | | | 100 | 100 | 100 | 100 | - | 98...100 |
| 4.0 mm | | | 99.6 | 99.3 | 99.4 | 98.8 | Max. 10 | Max. 15 |
| 2.0 mm | | | 81.2 | 84.5 | 80.2 | 85.5 | - | - |
| 1.0 mm | | | 49.3 | 49.1 | 49.8 | 77.3 | - | - |
| 0.63 mm | | | 37.6 | 34.9 | 36.0 | 72.7 | - | - |
| 0.25 mm | | | 20.0 | 14.1 | 9.0 | 28.8 | - | - |
| 0.1 mm | | | 14.4 | 7.4 | 2.9 | 5.7 | - | - |
| 0.063 mm | | | 9.3 | 3.8 | 1.7 | 1.2 | Max. 10 | - |
| Fine parts content | SR EN 933-1 | % | 9.3 | 3.8 | 1.7 | 1.2 | Max. 10 | Declared value |
| Real volumetric mass | SR EN 1097-6 | Mg/m³ | 2.60 | 2.60 | 2.60 | 2.50 | - | Declared value |
Table 2. Physical-Mechanical properties of aggregates size: 4-8 mm [Technical Documentation, Incertrans S.A.][2]

| Parameter determined | Test method | UM | Average value sort:4-8 mm | Technical conditions according to AND 605/2016 | Technical conditions according to SR EN 13043 |
|----------------------|-------------|----|--------------------------|-----------------------------------------------|-----------------------------------------------|
| Granulosity Passes on the sieve of: | | | | | |
| 16 mm | SR EN 933-1 | % | 100 | 100 | 100 | | | |
| 8.0 mm | | | 93.9 | 99.0 | 99.1 | Max. 10 | Max. 15 | |
| 6.0 mm | | | 44.4 | 82.0 | 76.6 | - | - | |
| 4.0 mm | | | 2.8 | 4.0 | 9.6 | Max. 10 | Max. 35 | |
| 2.0 mm | | | 0.4 | 2.0 | 0.6 | - | Max. 5 | |
| Fine parts content | SR EN 933-1 | % | 0.1 | 0.25 | 0.1 | Max. 1 | Declared value |
| Shape coefficient | SR EN 933-4 | % | 12.3 | 9.0 | 11.8 | Max. 25 | Declared value |
| Real volumetric mass | SR EN 1097-6 | Mg/m³ | 2.70 | 2.70 | 2.68 | Min. 2.65 | Declared value |
| Water absorption | SR EN 1097-6 | % | 0.50 | 0.50 | 0.95 | Declared value | Declared value |

Table 3. Physical-Mechanical properties of aggregates size: 8-16 mm [Technical documentation, Incertrans S.A.][3]

| Parameter determined | Test method | UM | Average value sort:5-16 mm | Technical conditions according to AND 605/2016 | Technical conditions according to SR EN 13043 |
|----------------------|-------------|----|--------------------------|-----------------------------------------------|-----------------------------------------------|
| Granulosity Passes on the sieve of: | | | | | |
| 16.0 mm | SR EN 933-1 | % | 94.2 | 100 | 100 | Max. 10 | Max. 15 | |
| 14.0 mm | | | 72.0 | 94.3 | 88.2 | - | - | |
| 12.5 mm | | | 49.3 | 76.6 | 73.8 | - | - | |
| 10.0 mm | | | 13.8 | 37.0 | 36.6 | - | - | |
| 8.0 mm | | | 1.1 | 4.0 | 8.9 | Max. 10 | Max. 35 | |
| Fine parts content | SR EN 933-1 | % | 0.45 | 0.20 | 0.25 | Max. 0.5 | Declared value |
| Shape coefficient | SR EN 933-4 | % | 11.0 | 10.0 | 11.9 | Max. 25 | Declared value |
| Real volumetric mass | SR EN 1097-6 | Mg/m³ | 2.70 | 2.72 | 2.69 | Min. 2.65 | Declared value |
| Water absorption | SR EN 1097-6 | % | 0.30 | 0.50 | 0.60 | Max. 2 | Declared value |
| Freeze-thaw resistance Magnesium sulfate test | SR EN 1367-2 | % | 0.50 | 0.60 | 1.50 | Max. 6 | Declared value |
| Resistance to fragmentation with the Los Angeles machine | SR EN 1097-2 | % | 18.4 | 14.0 | 23.5 | Max. 20 | Declared value |
| Micro-Deval wear resistance | SR EN 1097-1 | % | 11.5 | 6.4 | 10.8 | Max. 15 | Declared value |
Table 4. Affinity of bitumen type 70/100 pen to aggregate used [Technical documentation, Incertrans S.A.] [2],[10]

| Nr. crt. | Bitumen type            | Petrographic nature         | Number of aggregates not covered with bitumen (pcs.) | Affinity with bituminous binders% |
|---------|-------------------------|-----------------------------|------------------------------------------------------|----------------------------------|
| 1       | Bitumen 70/100          | Dolomitic limestone         | 10                                                   | 93.0                             |
|         | Bitumen 70/100          | Andesite                    | 9                                                    | 94.0                             |
|         | Bitumen 70/100          | Crushed gravel for bed river| 29                                                   | 80.7                             |

3. Asphalt mix design used

In this study 3 (three) asphalt mix designs were used, consisting of the aggregates whose characteristics were presented in Tables 1, 2 and 3. The aggregate dosages used to design the BA 16 rul 70/100 pen with dolomite limestone, andesites and aggregates from riverbeds are listed in Table 5. The optimal bitumen content of the asphalt mix is 5.9 %.

Table 5. Aggregate dosages for asphalt mix BA 16 rul 70/100.

| Aggregate size:          | Percentage BA 16 rul 70/100 pen with dolomitic limestone | Percentage BA 16 rul 70/100 pen with andesitic aggregates | Percentage BA 16 rul 70/100 pen (PC) with aggregates from rivers |
|-------------------------|----------------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------|
| Size 8-16 mm            | 24                                                       | 25                                                       | 25                                                            |
| Size 4-8 mm             | 28                                                       | 25                                                       | 25                                                            |
| Crushed sand 0-4 mm     | 30                                                       | 30                                                       | 30                                                            |
| Natural sand 0-4 mm     | 10                                                       | 10                                                       | 10                                                            |
| Filler                  | 8                                                        | 10                                                       | 10                                                            |
| Total                   | 100                                                      | 100                                                      | 100                                                           |

4. Laboratory tests performed on the asphaltic mixture

In this study, developed in the INCERTRANS SA laboratory, tests were carried out on the three types of BA16 rul 70/100 pen asphalt mixture in terms of bulk density (according to SR EN 12697-6), the volume of voids at 80 rotations according to SR EN 12697-8), Marshall stability (according to SR EN 12697-34), flow index (according to SR EN 12697-34), water absorption (according to Annex B of AND 605-2016), resistance to permanent deformations (according to SR EN 12697-25), IT-CY stiffness modulus (according to SR EN 12697-26) and water sensitivity (according to SR EN 12697-12).

5. Results obtained

Figures 1 to 8 show the results obtained from the tests presented in chapter 4 together with their classification in the performance categories according to the standard SR EN 13108-1 as well as within the limits imposed by the normative AND 605-2016.

After studying the results, it is concluded that the best characteristics for the BA16 rul 70/100 asphalt mix used in the wear layer are offered by the andesitic aggregates.
Figure 1. Bulk density for BA 16 rul 70/100 pen with the 3 types of aggregates

Figure 2. The volume of voids at 80 rotations by gyratory compactor for the recipe BA 16 rul 70/100 pen with the 3 types of aggregates

Figure 3. Marshall stability for the recipe BA 16 rul 70/100 pen with the 3 types of aggregates
Figure 4. Marshall flow (flow index) for the BA 16 rul 70/100 pen with the 3 aggregate types

Figure 5. Deformation at 50°C, 300 KPa and 10,000 pulses (dynamic creep) for the BA 16 rul 70/100 with the 3 types of aggregates

Figure 6. Deformation speed at 50°C, 300 KPa and 10,000 pulses (dynamic creep) for the BA 16 rul 70/100 with the 3 types of aggregates
Figure 7. The IT-CY stiffness module at 20°C for the BA 16 rul 70/100 pen with the 3 types of aggregates

Figure 8. Water sensitivity for the BA 16 rul 70/100 pen with the 3 types of aggregate

6. Conclusions

As is known, hot mix asphalt is a building material made by a process involving the heating of natural aggregates and bitumen, mixing of the mixture, transport and putting into operation by hot compaction [1].

To produce asphalt mixtures, a wide variety of mineral aggregates are used. Thus, there is a general concern to establish the optimal combination of bitumen and aggregates that give an asphalt mix that can be used as a road layer with the highest possible lifetime.

The quantity of aggregates in asphalt mixes is almost 94–95%, so the knowledge of the mineralogical-petrographic and physical-mechanical characteristics of these aggregates can lead to the improvement of the mix properties.

The most important physical-mechanical characteristics of the aggregates are: granularity, fine particle content, Los Angeles fragmentation resistance, Micro-Deval wear resistance, freeze-thaw resistance, flattening coefficient and shape coefficient.

The volume of voids at 80 rotations affects the wear resistance. The results of the analysis were between 1.1% and 3.1%, falling within the limit imposed by AND 605-2016 (min 0.5% and max 5% for the wear layer on technical class I and II roads).

The BA 16 mixture 70/100 made with andesite aggregates showed a better behavior than the mixture made with dolomite limestone aggregates as well as that with riverbeds aggregates.

In this study we can see how aggregates that have a Los Angeles fragmentation resistance and good Micro-Deval wear influence positively the performance of the asphalt mix in terms of Marshall stability and stiffness modulus; thus, the mixture with andesite aggregates yielded the best values of Marshall stability category MSmin7.5 (value 8.6 KN) compared to that achieved with limestone-dolomite aggregates category MSmin7.5 (value 7.8 KN) and with the mix design made with aggregates from riverbeds where category is MSmin5.0 (value 7.2 KN).
In terms of stiffness modulus, it exceeded 4,200 MPa, a limit imposed by AND 605 on all three recipes of mixes. The highest modulus of stiffness was obtained at the mixture made with andesitic aggregates, respectively, category S_{min} 5500 (5767 MPa value), where the value of fragmentation LA = 14% and wear resistance MD = 6.4% compared to the mixture made with limestone aggregates - dolomites where the stiffness module has the category S_{min}4500 (5410 MPa value) and the fragmentation strength LA = 18.4% and the wear resistance MD = 11.5%. The lowest value of the rigidity module, namely the S_{min}4500 category (4579 MPa value), was obtained in the mix with the riverbed aggregates, where the value of fragmentation LA = 23.5% and the wear resistance MD = 10.8%.

The resistance to permanent deformations represented by deformation and deformation velocity at 50°C to 300 KPa and 10,000 pulses was within the limits imposed by AND 605: 2016, respectively, the deformation being max. 20,000 μm / m and max.1.0 μm / m / cycle. Mixtures made with quarry aggregates showed much better deformations of 11,250 μm / m and a deformation velocity of 0.6 μm / m / cycle compared to the mixture obtained with aggregates from beds rivers where the deformation was 17,585 μm / m and the speed of deformation was 0.8 μm / m / cycle.

Regarding water sensitivity (ITSR) this was within the limit imposed by min. 80% at all 3 asphalt mixtures. The results are varied, so although the water absorption was the same as in the case of andesite aggregates and dolomite limestone at the 4-8 mm range of 0.5% and lower in dolomite limestone aggregates at the 8-16 mm range of 0, 3% versus 0.5% in andesites aggregates, the best value for water sensitivity was obtained on the mixture made with andesitic aggregates (ITSRmin85 category having the value of 86.7%) compared to the mixture made with dolomite limestone aggregates where we have the ITSRmin80 category, having the value of 81.1%. The mixes made with quarry aggregates showed much better values than the mixture made with aggregates from riverbeds.

Aggregate characteristics also determine the performance of the mixes, so the use of quarry aggregates and a bituminous binder that meets technical conditions leads to an increase in the performance of mixes made with quarry aggregates (especially andesites) compared to asphalt mix with aggregates from riverbeds. Subsequent investigations with different bitumen values and the expansion of aggregate sources as well as types of asphalt mixes are necessary in order to have some more general conclusions on how the technical characteristics of the different types of aggregates influence the performance of the mixes.

References

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