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INFLUENCE OF AGGREGATE GRADATION ON HMA MIXES STABILITY

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Abstract

The load transfer capacity of pavements is to a great extend influenced by aggregates. About 85% of the total volume of hot mix asphalt (HMA) mixtures consists of aggregates; thus, they are greatly influenced by aggregate properties like angularity (shape), roughness (texture), and gradation. Aggregate gradation controls the structure of voids. Current specifications for aggregate properties in HMA pavements require the aggregate blend to fall within a specified range of gradation values. Although the abovementioned requirement has ensured the construction of high quality HMA pavements, the properties are largely empirical and they are not based on performance-related tests. Marshall Stability is in principle the resistance to plastic flow of cylindrical specimens of a bituminous mixture loaded on the lateral surface. It is the load carrying capacity of the mix at 60^{o}C. Aggregates with different gradations from the broader area of Xanthi, Northern Greece, have been used to prepare specimens for stability testing of hot asphalt mixtures in the laboratory. The research focused on the evaluation of the influence of aggregates in the overall stability characteristics of the mixtures. The maximum stability value has been obtained with an open-graded mixture having 5% asphalt and aggregate size 2.36 mm. However, the stability of the dense graded mixture is higher than this maximum value.

Keywords: pavement, hot mix asphalt, aggregates, stability, open-graded.

1. INTRODUCTION

The gradation or particle size distribution of an aggregate is one of the prominent aggregate characteristics in determining how it will perform when used as a pavement material. In hot mix asphalt (HMA), gradation helps determine almost every important property including stability, stiffness, fatigue resistance, durability, workability, frictional resistance, permeability and moisture susceptibility [1]. Respectively, in Portland cement concretes (PCC), gradation helps determine strength, durability, porosity, shrinkage, workability and water and cement requirements. Due to its role, gradation is a primary concern in PCC and HMA mix design leading to the necessity to specify allowable aggregate gradations.

Maximum aggregate size can affect HMA, base and subbase courses in a number of ways. In HMA, instability may result from excessively small maximum sizes, while poor workability as well as segregation may result from excessively large maximum sizes. The max aggregate size is defined in ASTM C 125 as the smallest sieve through which 100% of the aggregate sample particles pass. Nominal maximum size is defined as the largest sieve that retains some of the aggregate particles but generally not more than 10 percent by weight. Thus, it is important to specify to which maximum reference is being made.

The best gradation is difficult to be defined, since it is a complex estimation process depending on the material's properties, the loading and environmental conditions as well as the mix characteristics and the pavement section where it will be laid [2]. To classify gradation, several terms are used, like dense or well-graded, gap graded, open-graded, or uniformly graded [3]. These classes share common characteristics and do not precisely and strictly define division limits.

Open graded asphalt is used as a wearing course to provide increased safety in wet weather (through reduced surface water and spray during rain) and reduced noise levels, up to 6 dB(A) [4, 5]. Open graded asphalt is a porous asphalt mix formulated to provide large voids (in excess of 20%) to allow surface water to drain away and hence increase safety for the motorist.

Open-graded mixtures are used for different reasons in the European countries and the United States of America. The scope in European specifications is to have a surface layer producing less tire-pavement noise through the excess voids in comparison with dense graded asphalt mixtures. The placement of open-graded mixes in US is mainly done in order to improve the permeability of the pavement and, as a result, the friction of its surface in wet weather conditions. The voids content in porous mixes employed in various countries in Europe range between 20 and 25 percent, being clearly higher than those in the US designs where air voids are not more than 20 percent [6, 7].

European countries, such as UK, Sweden or Switzerland have specifications for horizontal and vertical permeability, while there are no permeability specifications in the US [8]. However, in both continents, a maximum particle loss of 50 percent from the Los Angeles abrasion test is specified. To have a complete picture of the differences in specified engineering properties, it must be stated that very few American states specify a tensile strength ratio for porous mixes (usually above 80%), while in Europe this ratio is specified as at least 50%.

Open graded asphalt concrete (OGAC) is a surface course having an aggregate gradation that provides an open void structure. Air void content typically ranges between 15 to 25% resulting in a highly permeable mixture. The principal benefit derived from OGAC is a significant reduction in splash and spray and a reduction in tire-pavement noise and an increase in the frictional characteristics relative to dense graded mixtures [9].

The use of open-graded friction courses (OGFCs) goes back in 1950’s in the United States of America, where is also met under other names, like plant mix seal, asphalt concrete friction course, PEM (Permeable European Mix) or popcorn mix. Its placement helped to improve the surface frictional resistance of asphalt pavements. The mechanism for the allowance of water to drain away from the roadway is based to the porous structure of the asphalt layer [10, 11]. So, in wet weather the driving conditions are dramatically improved, since hydroplaning during rainfall is almost eliminated, spray behind vehicles and splash are reduced, the pavement friction is improved, and, along with the absorption of noise in air voids, an ameliorated surface reflectivity is ensured. Other advantages offered by open-graded friction courses are the increased visibility of pavement markings, mitigation of bleeding and flushing, and the high skid resistance on wet pavement surfaces resulting from the macro-texture characteristics of the OGFC surface and maintained at high operating speeds.

However, these mixtures are not implemented in a generalized manner due to difficulties arising during construction and some deficiencies encountered in service performance. These drawbacks could be attributed to some uncertainties found in existing design methods [12].

A laboratory investigation has been designed and performed on the characteristics of open-graded mixes in order to estimate mixture properties, such as the stability as measured by the Marshall apparatus. The results, properly assessed and interpreted could lead to guidance for structures functioning under Greek environmental and traffic conditions, as well as to the prescription of specifications referring to local aggregate quality features.

2. LABORATORY INVESTIGATION

The materials used in the laboratory study were paving grade asphalt and crushed limestone aggregates from a quarry in Xerias area, of the Kavala Territorial District. Five different aggregate material compositions were selected, one for dense-type gradation according to the Greek specifications, and the rest for open-graded mixtures. The dense type synthesis along with the limit values curves is shown in Figure 1.

The grain size distribution of the materials used for the preparation of open-graded mixtures is given in Figure 2. Marshall Specimens [13] were prepared with asphalt contents 4, 4.5, 5, and 5.5%. For each percentage of asphalt, 3 specimens were formed with 75 blows on each face of the specimen.

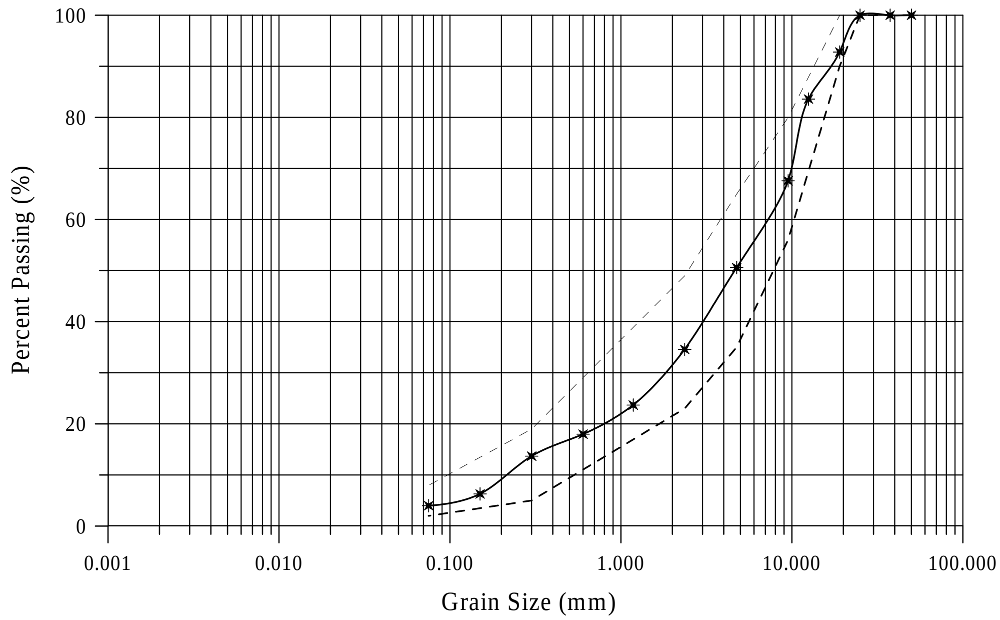

Figure 1. Grain size distribution for the aggregate composite (dense gradation)

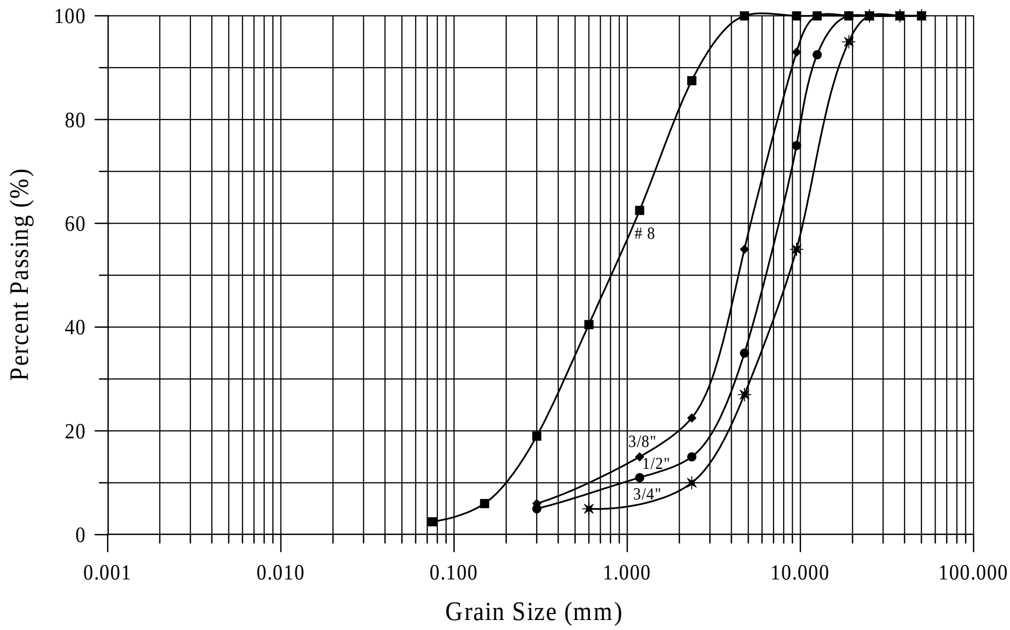

Figure 2. Grain size distribution of the aggregates for the open graded mixtures

The results for the dense-graded samples are given in graph form in Figures 3 to 6. When percent asphalt used for the preparation of specimens increased, the stability increased with max stability value 12.95% at 5% asphalt. There were less air voids in mix samples with higher asphalt content; the values were found in that occasion at a range between 1.38% and 4.91%.

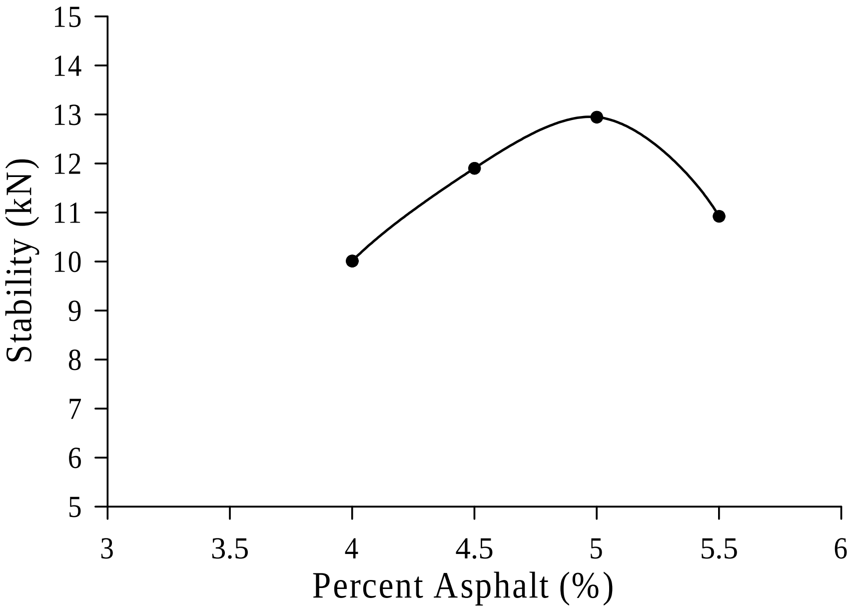

Figure 3. Stability versus percent binder for the aggregate (dense gradation)

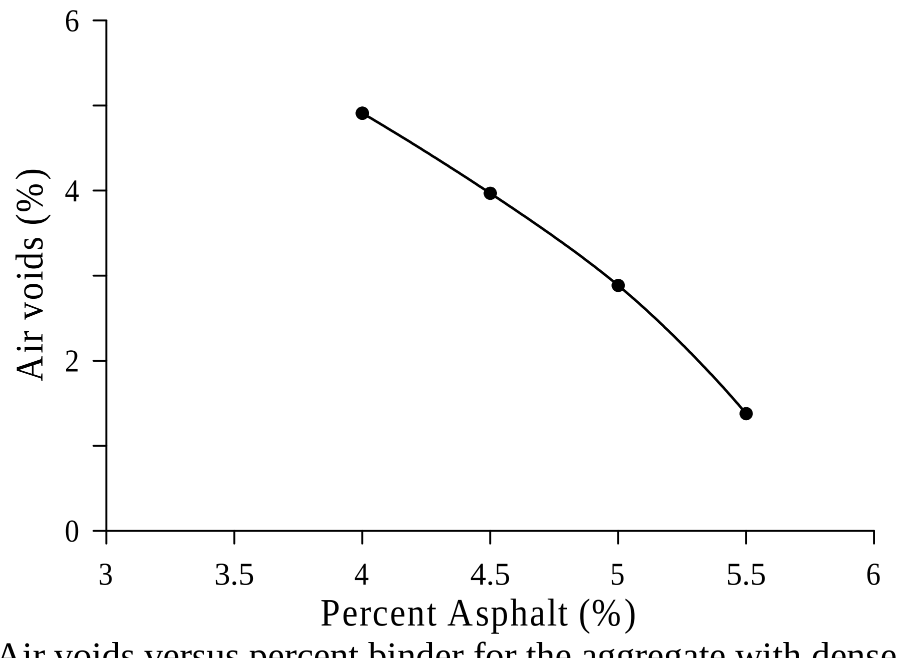

Figure 4. Air voids versus percent binder for the aggregate with dense gradation

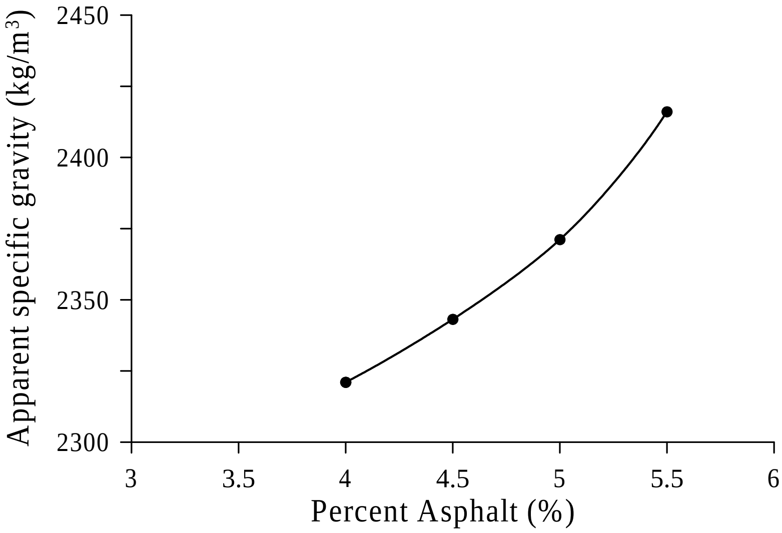

Figure 5. Apparent specific gravity versus percent binder for the aggregate with dense gradation

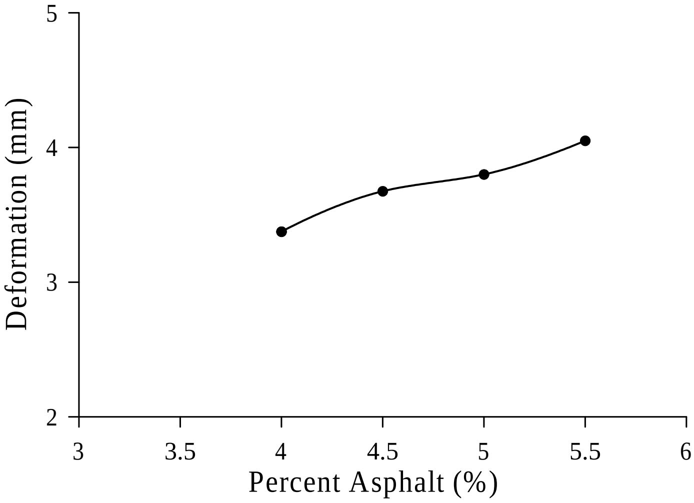

Figure 6. Deformation versus percent binder for aggregate with dense gradation

The trend for the apparent specific gravity was to increase with asphalt content ranging from 2321.04 to 2416.06 kg/m^3. The deformation values gradually increased with the percentage of binder.

The stability values for the open graded mixtures are given in Figures 7, 8, 9 and 10 for 19 mm, 12.5 mm, 9.5 mm and 2.36 mm, respectively.

The maximum stability value is obtained with a mixture having 5% asphalt and aggregate size 2.36 mm. In any case, the stability of the dense mixture is higher than this maximum value.

Referring to the air voids in the mixes, the values were higher in the case of open gradation than those of the dense mixture. The higher scale of air voids values has been observed for the samples with aggregates having maximum grain size 2,36 mm, while the lower percentage of air voids has been recorded when aggregates with maximum grain size of 19 mm were used.

The air voids ranged from 11.27 to 14.13%, 14.19 to 18%, 14.53 to 17.14% and 16.4 to 21.16% in the case of max grain sizes of 19, 12.5, 9.5, and 2.36 mm, respectively.

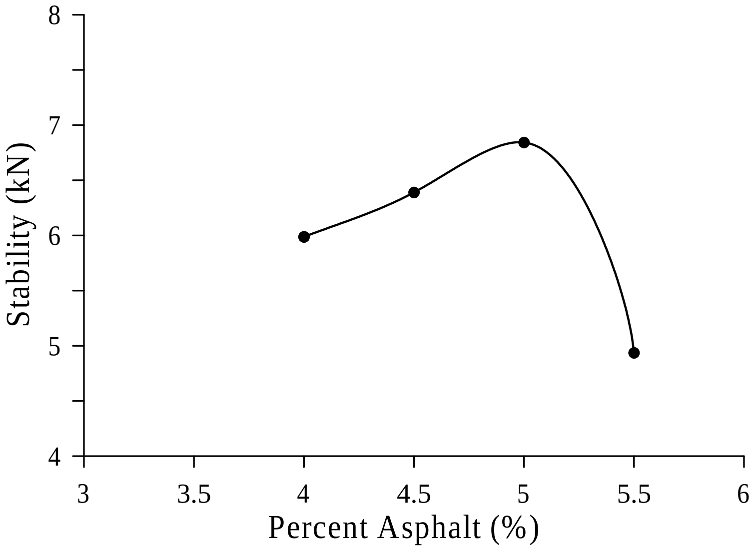

Figure 7. Stability versus percent binder in open graded mix (max grain size 19 mm)

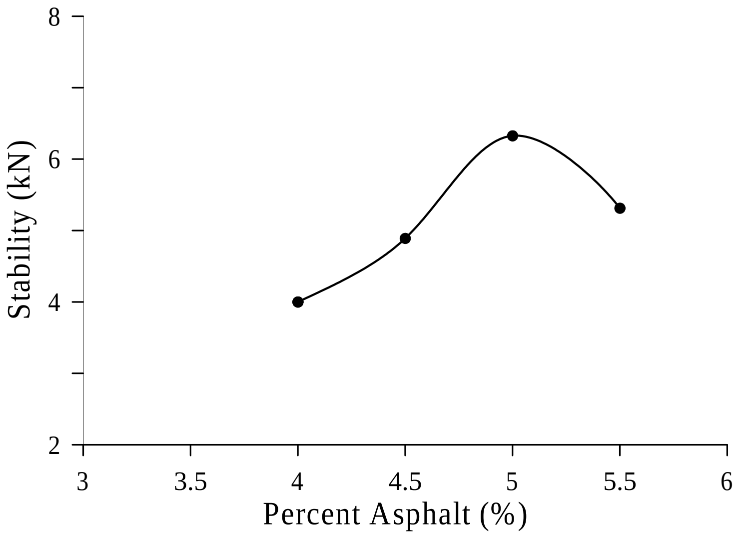

Figure 8. Stability vs. percent binder in open graded mix (max grain size 12.5 mm)

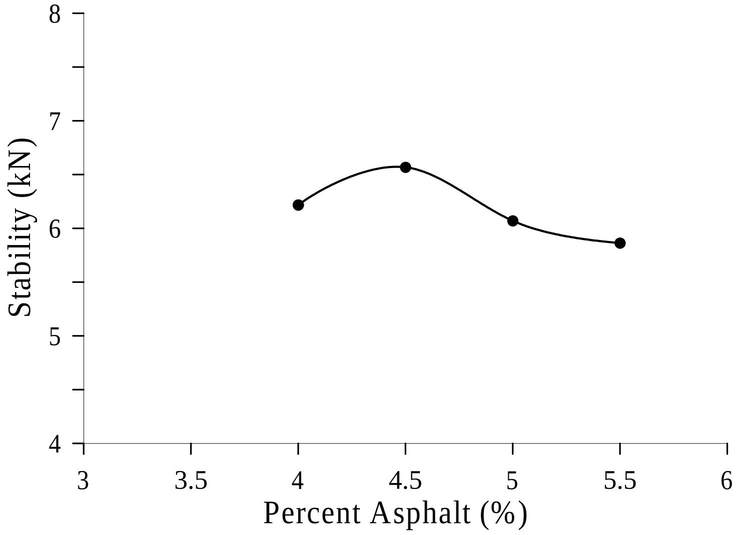

Figure 9. Stability versus percent binder in open graded mix (max grain size 9.5 mm)

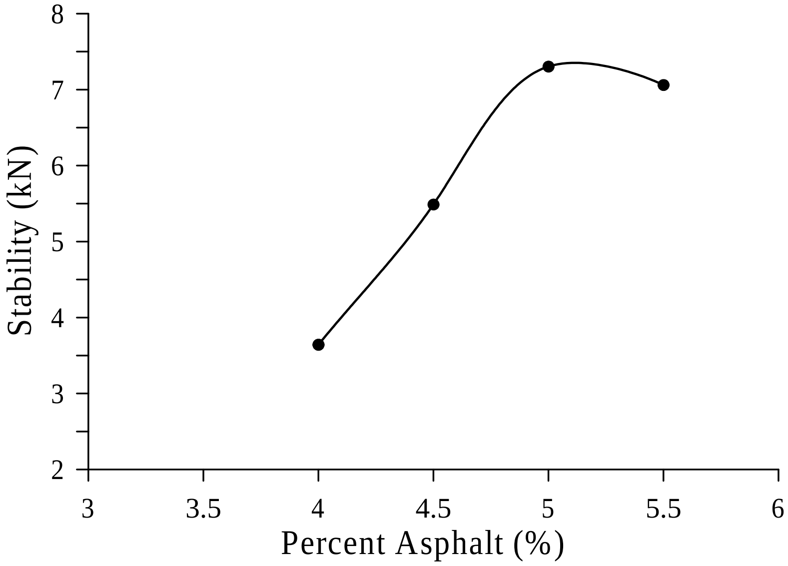

Figure 10. Stability vs. percent binder in open graded mix (max grain size 2.36 mm)

The deformations obtained were of about the same order of magnitude and the variation of the values was between 10 and 18 mm.

3. CONCLUSIONS

When the option is to use open-graded asphalt mixtures in pavement constructions, then various benefits arise for both the transportation facility and the road users. The choice of such mixes for use in surface courses during the initial pavement construction or in a maintenance phase later in its life (a) improves the surface frictional resistance; (b) enhances the drainage characteristics; (c) alters dramatically the driving conditions reducing hydroplaning, spray behind vehicles and splash during rainfall; (d) absorbs the tire-pavement noise; (e) leads to an improved surface reflectivity and increased visibility of pavement markings; (f) mitigates asphalt bleeding and flushing on the surface, and (g) offers high skid resistance on wet pavement.

Through the use of laboratory tests, it has been shown that the stability of open graded mixtures is lower than the stability of dense graded mixtures, regardless the percent of binder used.

The optimum asphalt content has been found to be approximately 5%, with the exception of the mix with aggregates having maximum grain size 9.5 mm, where the optimum was about 4.5%.

The maximum stability value has been obtained with an open-graded mixture having 5% asphalt and aggregate size 2.36 mm. However, the stability of the dense mixture is higher than this maximum value.

The research effort could be extended to more aggregate sources and different asphalt grades, if the formation of Greek specifications on open-graded mixtures is foreseen in the near future, as well as in designing more effective noise-reducing and of higher drainage quality asphalt courses.

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