MECHANICAL PROPERTIES OF BASALT AGGREGATES UNDER THE REPEATED LOADS

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ABSTRACT

To achieve durable and sustainable road pavements, aggregates in pavement layers should have appropriate physical and mechanical properties. Nowadays, because of some weaknesses of conventional limestone aggregates, igneous rocks have become more used in Turkey by the means of highway pavement layers. Igneous rocks are widespread in Central Anatolia Region of Turkey. Also, Basalt is the most common type of igneous rocks. This paper reports the results of experiments, aiming to identify the physical and mechanical properties of basalt aggregates under the repeated tire loadings when it is used as an aggregate for preparation of base layers. Basalt samples are collected from six different points of central Anatolia in Turkey. The experimental program consisted of two stages: study of the physical and chemical properties of basalt and study of the mechanical properties of specimens made with basalt aggregate. In the laboratory, cylindrical specimens prepared with basalt and limestone was tested in Repeated Load Triaxial (RLT) test apparatus. Resilient modulus and permanent deformation values of the specimens were determined. Prior to RLT testing particle size analysis, micro-Deval test, aggregate impact value test, abrasion test, frost resistance test, compaction test, California Bearing Ratio (CBR) test were performed on the materials. The physical and mechanical properties of basalt are compared with conventional crushed limestone according to relevant standards. The test results indicate that the physical properties of basalt aggregate offers advantages compared to limestone aggregates. Basalt has a high abrasion resistance, high durability and high bearing ratio, on the other hand, the water absorption of basalt aggregate is partially high.

Keywords: Basalt aggregate, Repeated load triaxial test, Resilient modulus, Asphalt pavements

INTRODUCTION

Basalt is the most common type of extrusive igneous rock at the Earth’s surface. Most basalt is volcanic in origin and was formed by the rapid cooling and hardening of the lava flows. Igneous rock is one of the three main rock types, the others being sedimentary and metamorphic rock. Igneous rock is formed through the cooling and solidification of magma or lava. Igneous rock may form with or without crystallization, either below the surface as intrusive (plutonic) rocks or on the surface as extrusive (volcanic) rocks. Over 700 types of igneous rocks have been described, most of them having formed beneath the surface of Earth's crust. These have diverse properties, depending on their composition and how they were formed (Le Maitre, 2002). The upper 16 kilometres (10 miles) of Earth's crust is composed of approximately 95% igneous rocks with only a thin, widespread covering of sedimentary and metamorphic rocks (Klein et al., 1985).

Basalt is a stiff, durable, grey and black colored volcanic rock and it is commonly available in nature and spread over different localities in Turkey. Basalt can be used in many industrial applications such as: rock wool, pipes, moulds, and as construction materials. Basalt rocks are commonly used as construction materials such as aggregate in concrete and asphalt, rock filling in dams and breakwaters, crushed gravel in railway ballast and airway foundation (Goodman, 1993).

Most basalts are dark gray or black, but some are light gray. Various structures and textures of basalts are useful in inferring both their igneous origin and their environment of emplacement. Basalts are the predominant surficial igneous rocks on the Earth. Many physical properties of basalt have been measured in the field and laboratory (Fookes, 1980;

Korkanc and Tuğrul, 2004; Karakuş, 2011; Çopuroğlu et al., 2009). Some studies dealing with basalt has been concluded that basaltic aggregates increase the quality of concrete (Tasong et al., 1998; Özturan and Çeçen, 1997).

The physical properties of basalts vary greatly because of the range of textures and compositions. Flowing temperature of basalt ranges from 1,000 to 1,220 °C. (Ibrahim et al., 2009). The mineralogy and texture of basalts vary with cooling history and with chemical composition. With slow cooling, crystals grow to large sizes reaching to few millimeters. In basaltic melt, diffusion may limit the rate at which a given crystal-liquid boundary can move because the crystals differ in composition from the melt. If crystallization is forced at a rapid rate by rapid cooling, either the crystals will have high ratios of surface area to volume (needles, plates) or many seeds (nuclei) will develop. Crystals which grow rapidly under strongly super cooled conditions have different compositions from those which form if slower cooling prevails. Consequently, the same basalt flow may contain different minerals in variously cooled parts of the flow.

Figure 1 Crushed basalt

The aim of this study is to determine performance of basalts used as base and sub-base aggregate in highways. For this reason, physico-mechanical tests were performed on the basalt samples. The aggregate properties; fine materials, aggregate shape, physical properties, durability, abrasion, frost susceptibility, and mechanical performance under the Repeated Load Triaxial (RLT) experience has been investigated. Besides, basalts were compared with conventional crushed limestone with respect to aggregate quality. Volcanic rocks are widespread in Central Anatolia Region of Turkey. However the use of basalts as aggregate material is limited in Turkey. Basalts are likely to continue to be the alternative source for crushed rock aggregate in the future.

LABORATORY ANALYSES

Basalt aggregates collected from the town of Kayı located approximately 15 km north of Isparta, Turkey. Firstly, the basalt aggregate is required to include no organic materials and clay lumps and also be “non-plastic”. Therefore, experiments of liquid and plastic limits in the aggregate and the dust samples were carried out on the basis of TS 1900 and according to the test result the material was stated to be non-plastic.

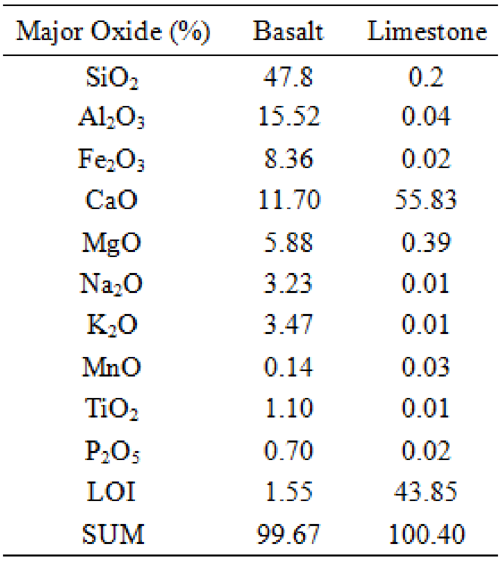
CHEMICAL COMPOSITION OF THE BASALT AGGREGATE

In order to determine chemical characteristics of the studied basalt chemical analyses were performed. The major element oxides were determined by XRF (X-ray fluorescence). The results of the chemical analyses were given in Table.1. The basalt was then classified according to Le Maitre et al., (1989) by using their Na_2O+K_2O and SiO_2 contents. According to the classification, basalt is stated as trachy-basalt.

GRADATION

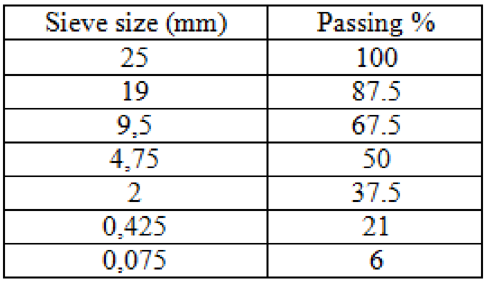
Sieve analysis carried out according to TS 7043 EN 13450 and shown in Table. 2. As seen in table the mixture consists of 50% coarse aggregate and 50% fine aggregate in weight. The selected aggregate gradation was in accordance with the General Directory of Turkish Highway (GDTH) recommended gradation for granular base layers.

Table 1 The Chemical Analysis of Basalt Aggregate



Major Oxide (%)	Basalt	Limestone
SiO_2	47.8	0.2
Al_2O_3	15.52	0.04
Fe_2O_3	8.36	0.02
CaO	11.70	55.83
MgO	5.88	0.39
Na_2O	3.23	0.01
K_2O	3.47	0.01
MnO	0.14	0.03
TiO_2	1.10	0.01
P_2O_5	0.70	0.02
LOI	1.55	43.85
SUM	99.67	100.40

Table 2 Gradation of aggregate mixture



Sieve size (mm)	Passing %
25	100
19	87.5
9,5	67.5
4,75	50
2	37.5
0,425	21
0,075	6

PHYSICAL AND MECHANICAL PROPERTIES OF THE BASALT AGGREGATE

Physical and mechanical properties of the basalts were determined by a variety of laboratory tests. At least three tests were carried out for each property and the mean values were obtained. The specific density of basalt ranges between 2.79 and 2.91 kg/cm^3. The density of the basalt aggregate is higher than the limestone. The water absorption of the basalts ranges between 2.0% and 2.06% (Table 3).

Table 3 Physical and mechanical properties of aggregates

Aggregate Property	Basalt		Limestone	
Specific gravity	Fine	Course	Fine	Course
	2.91	2.79	2.70	2.67
Specific bulk density	2.81	2.64	2.68	2.65
Water absorption, %	2.0	2.06	0.48	0.34
Freeze-thaw loss,% (with Sodium Sulphate)	1.10		2.45	
Loose unit weight	1.70		1.81	
Rooded unit weight	1.82		1.86	
Aggregate impact value, %	7.0		12.0	
LA Abrasion loss, %	8.0		21.0	
Mikro-Deval abrasion loss, %	8.0		15.0	
CBR, %	200		145	

Freeze-Thaw Loss with Sodium Sulphate

This test is accelerated method of the freeze-thaw test and applies by using sodium sulphate solutions. Crystallized sodium sulphate (Na_2SO_4) was used in this study. The basalts were broken by using hammer or rock crusher and sieved with suitable size. Then they were separately put in a container and prepared for the test according to TS EN 1367-2. Freeze–thaw is one of the major problems in the region where the basalt aggregates are used. As seen in Fig.3, Na_2SO_4 soundness values of coarse aggregates range between 1.10% and 2.45%.

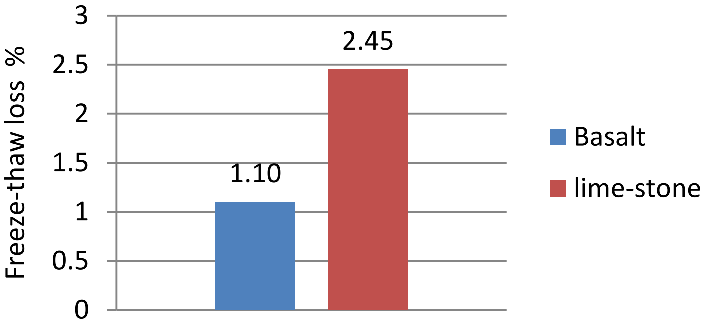


Figure 3 Freeze-thaw test results

Specific Gravity and Unit Weight

Loose unit weight and rodded unit weight of the aggregates determined according to TS 3529 test procedure (Fig.4). Specific gravity and water absorption of aggregates determined according to TS EN 1097-6 procedure (Fig.4 and 5).

Flakiness Index of Aggregates

Flaky and elongated particles may have adverse effects on bituminous mix. Aggregate particles are classified as flaky when they have a thickness (smallest dimension) of less than 0.6 of their mean sieve size. The flakiness index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test is not applicable to material passing a 6.30 mm test sieve or retained on a 63.0 mm test sieve. The flakiness index was determined according to the procedure given by BS 812: Part 105-1. The results are given in Table.3. As seen in this table, the flakiness index of the basalt aggregate is 25%.

In general, strong and hard or brittle rocks produce a higher proportion of flakes than weak rocks, although the latter generate more fines in crushing (Smith and Collis, 2001).

Abrasion Loss (Los Angeles and micro-Deval test)

Durability or resistance to wear or decay is a significant requirement of many aggregates. Los Angeles abrasion test was carried out in accordance with TS EN 1097-2 to determine abrasion value of the aggregates. Fig.6 shows the test results.

Two NCAT reports have shown that the micro-Deval test is a good indicator of coarse aggregate quality for aggregates that will be exposed to water (Cooley, 2002; Kandhal and Parker, 1998). The micro-Deval test provides predictive information about abrasion resistance and durability of aggregates. Unlike the LA Abrasion test, the micro-Deval test is performed in the presence of water. Some aggregates are weaker when they are wet. Mikro-Deval test was carried out in accordance with TS EN 1097-1 to determine abrasion value of the aggregates. Fig.6 shows the test results. Both LA and micro-Deval test results indicate that basalt has lower abrasion loss compared to limestone.

Aggregate Impact Value (AIV)

Tests are included in TS-EN 1097-2 Standard for measurement of the mechanical properties of crushed rock aggregate. In these test, samples ranging in size from 8 to 12.5 mm are subjected to shock. After 10 times loading the proportion of material passing 5 sieves is calculated as a percentage of the original sample weight, and expressed as the aggregate impact value. Values obtained in these tests are given in Fig.7. The tested aggregate impact value varies from 6.81% to 12.11%. Aggregate Impact Values (AIV's) below 10 are regarded as strong, and AIV's above 35 would normally be regarded as too weak for use in road surfaces. AIV values for both material tested are exhibit strong enough. Basalt aggregate has lower AIV values than limestone.

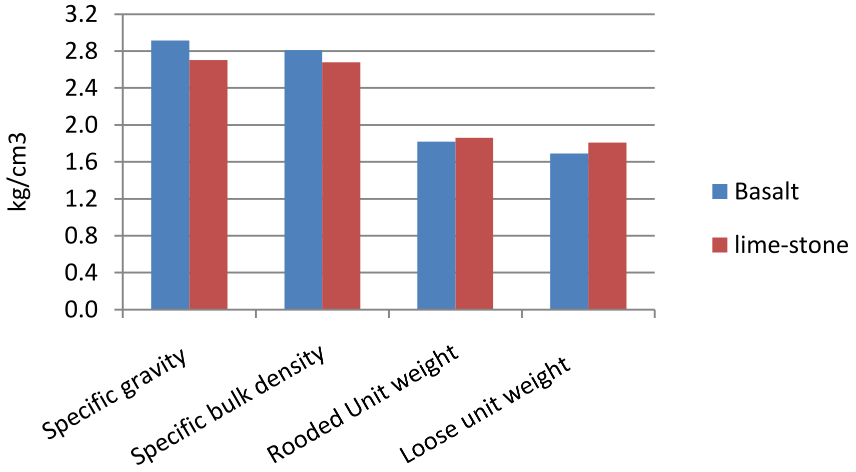


Figure 4 Specific gravity and unit weight of aggregates

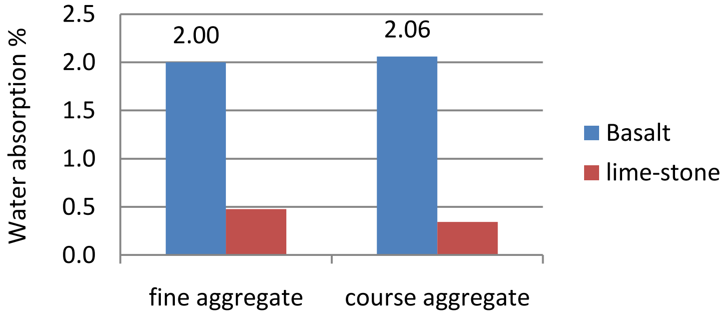
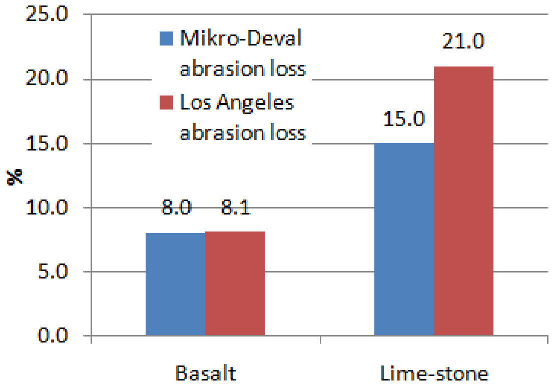


Figure 5 Water absorption of aggregates



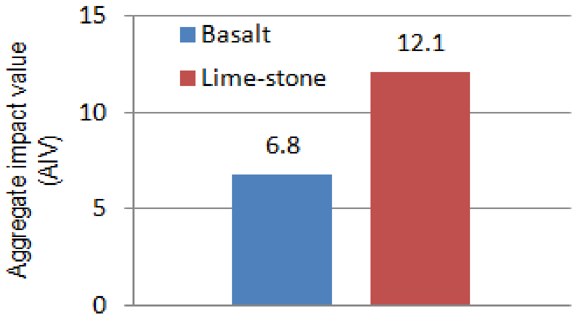


Figure 6 Los Angales and Micro-Deval abrasion loss

Figure 7 Aggregate impact value test results

Proctor Compaction Test

The modified Proctor compaction test was conducted on the materials to determine the moisture–density relationship. The test was conducted according to TS EN 13286-2 (150 mm diameter mold, five separate lifts of soil, 56 blows by a 4.5 kg hammer falling 45 cm). Fig.8 shows the moisture–density relationship for basalt material. Proctor tests on the basalt aggregate resulted in dry density value of 2.24 and optimum water content of 10.5%. Optimum moisture contents (W_{opt}) obtained from Proctor test results were used for compacting the RLT test specimen.

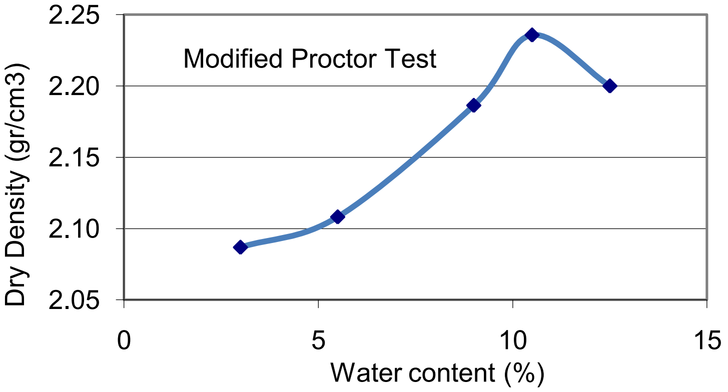


Figure 8 Moisture-density relation for basalt aggregate

Repeated Load Triaxial Test

Repeated load triaxial (RLT) test apparatus was used to determine the resilient modulus and permanent deformation values of the specimens. The RLT tests were carried out on drained specimens with the dimensions of 150 mm diameter and 300 mm height in Mehmet Akif Ersoy University's PC controlled RLT test apparatus (Yılmaz et al., 2008). This apparatus has a closed-loop hydraulic loading device.

The testing procedure followed for resilient modulus test is based on the AASHTO Test Method T294-94. This method recommends vibratory compaction of the specimen, but no exact specifications are provided for the number of aggregate layers, the amount of vibration energy and the duration of vibration (Zaman et al., 1994). In this research, a vibratory compactor shown in Fig.9b was used. The specimens were manufactured in five layers in a cylindrical split mold. Optimum moisture contents (W_{opt}) determined from the modified Proctor test was used in specimen preparation. After compaction the split mold was stripped and the specimens were equipped with platens in both ends. After a test specimen was fabricated, it was placed in the triaxial chamber and instrumentation attached.

The triaxial chamber was used to contain the test specimen and the confining fluid during the test. The triaxial chamber used in the resilient modulus testing is shown in Fig.9d. The axial deformation was measured by external LVDT. Air was used within the triaxial chamber as the confining fluid. For sample conditioning, the confining pressure was set to 103.4 kPa and 1,000 repetitions at a maximum deviatoric cyclic stress of 93.1 kPa were applied. Conditioning is necessary for establishing better contact between the specimen and load platens, and for developing a more homogeneous specimen. Following conditioning, the resilient modulus test was carried out according to the loading sequences. The loading sequences described in the AASHTO test protocol were used. For each material investigated, three specimens were compacted and tested. The results that are discussed here are averages for these three specimens.

Resilient Modulus Test Results

Resilient modulus is the most important variable to mechanistic design of pavement structures. It is the measure of pavement response in terms of dynamic stresses and corresponding strains. Resilient modulus (M_r) is determined from laboratory testing of cylindrical specimens and is calculated as the ratio of repetitive deviatoric stress (σ_d) and resilient strain, ε_r (Eq.1) (Uzan, 1985; Lekarp et al., 2000; Tutumluer et al., 2003). Resilient modulus values were calculated after 100 cycles of each loading sequences. The specimens were tested at min 95% of maximum dry density, which varied between 2.24 and 2.31 t/m^3. The water content was optimum.

$$M_r \frac{\sigma_1 - \sigma_3}{\varepsilon_r} = \frac{\sigma_d}{\varepsilon_r} \tag{1}$$

Where;
σ_d = the applied deviator stress
ε_r = resilient strain

The resilient modulus data were first fitted to the bulk stress model (Eq.2)

$$M_r = k_1.\theta^{\,k2} \tag{2}$$

$$\theta = \sigma_1 + \sigma_2 + \sigma_3 = \sigma_1 + 2\sigma_3 \text{ (Bulk Stress)}$$

In Eq.2, θ is the bulk stress (first stress invariant of the normal stress tensor) and k_1, k_2 are regression constants determined by statistical analysis of laboratory data. The bulk stress is equal to the sum of three principal stresses. Previous research has shown that higher quality granular materials exhibit larger k_1 values and smaller k_2 values (Brown and Pappin 1985).

The bulk stress model appears to fit the data reasonably well (see Fig.10) and it does show the stress dependency of resilient modulus in the material tested. At 20.7 kPa lower confining pressure, M_r values tend to go horizontal with bulk stress. Above 20.7 kPa confining pressure the M_r increased with bulk stress. The resilient modulus value for the tested materials varies between 113 - 355 mPa for basalt aggregate and 105 – 460 mPa for limestone depending on bulk stress (θ). However, basalt aggregate provides better results than limestone in the LA test, the frost resistance test, aggregate impact value test and the CBR test. The M_r values of limestone slightly higher than basalt aggregate (Fig.10). In Fig.11 and Fig.12 the relation between resilient modulus and deviatoric stress can be seen for each confining pressure level.

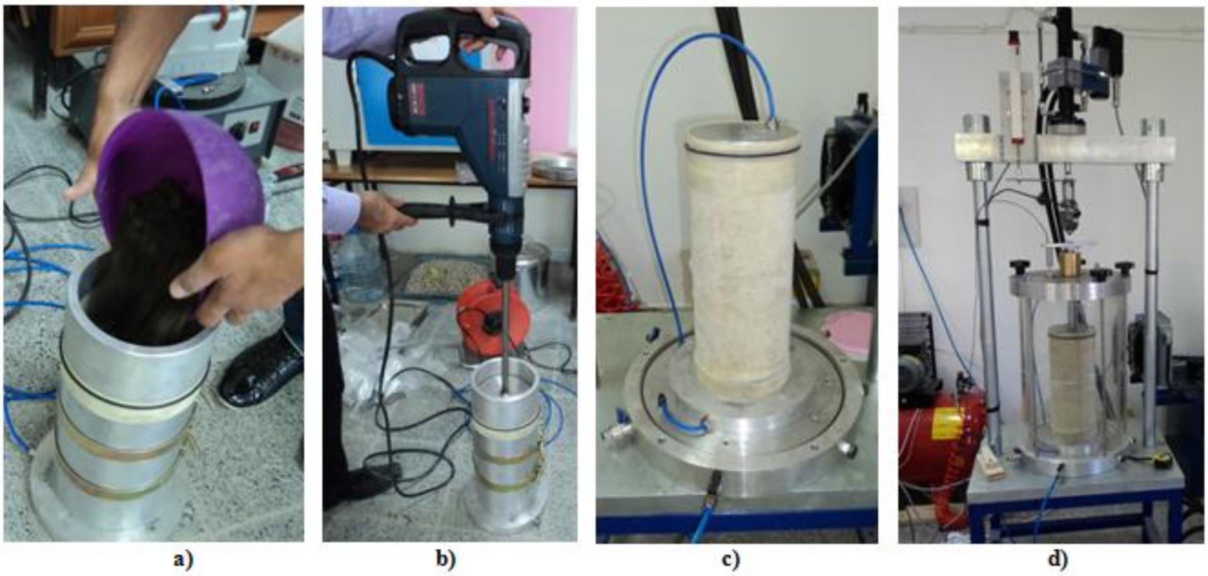


Figure 9 (a) Specimen preparation (b) Vibratory compaction (c) Compacted specimen (d) Triaxial chamber

Permanent Deformations

To determine the permanent deformation behavior of the studied materials, RLT tests were performed on cylindrical shaped specimens. The specimens were prepared in a similar method to the M_r test specimens. The stress level of 4 and 10,000 load cycles were carried out for permanent deformation test. Fig.13 and 14 show the test results at a constant confining pressure of 69 kPa for 207 kPa deviatoric stress.

The cumulative axial permanent strains versus the number of loading cycles are illustrated in Fig.13 on a log–log scale. Permanent axial strains accumulated from 10,000 load repetitions are in the range of 102.10^{-5} and 195.10^{-5} strain. The classic power-law model is typically used to simulate the test results.

Fig.14 illustrates the axial permanent deformations versus the number of loading cycles. It can be clearly seen that the magnitude of accumulated permanent deformations increases according to the increase in cycle repetitions. However, after the first 1,000 repetitions, permanent deformations increase slowly and the deformation curve slowly reaches a horizontal trend. The permanent deformation values for basalt aggregate were lower than limestone. Final permanent axial deformation value is 0.31 mm for basalt and 0.59 mm for limestone aggregate.

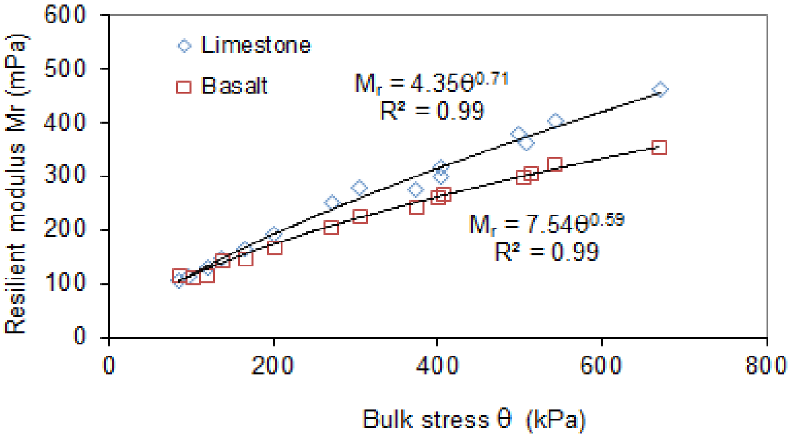


Figure 10 Resilient modulus vs Bulk stress and best fit curves

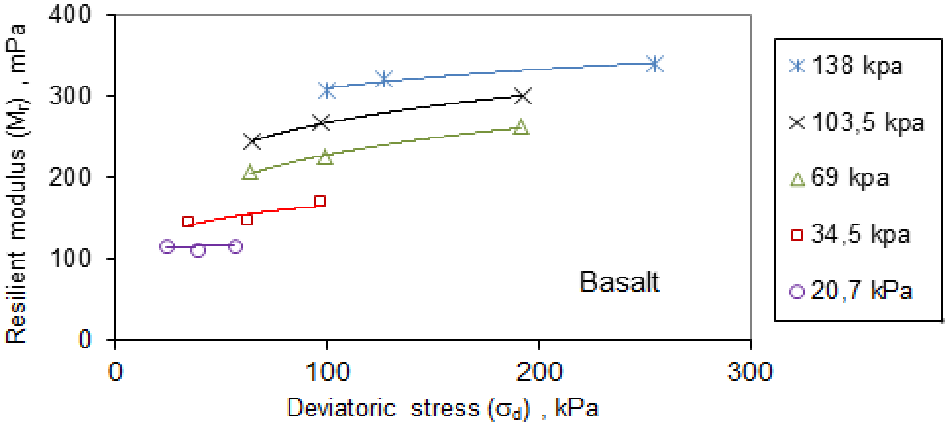


Figure 11 Resilient modulus vs. Deviatoric stress for basalt aggregate

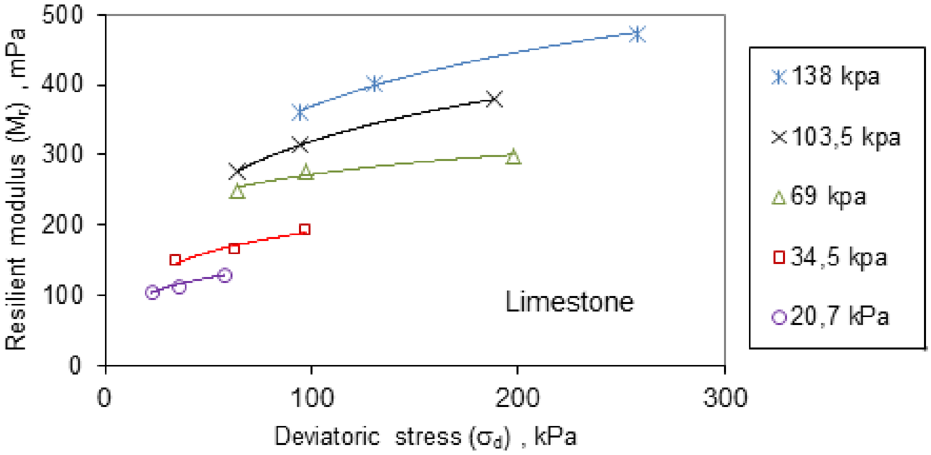


Figure 12 Resilient modulus vs. Deviatoric stress for limestone

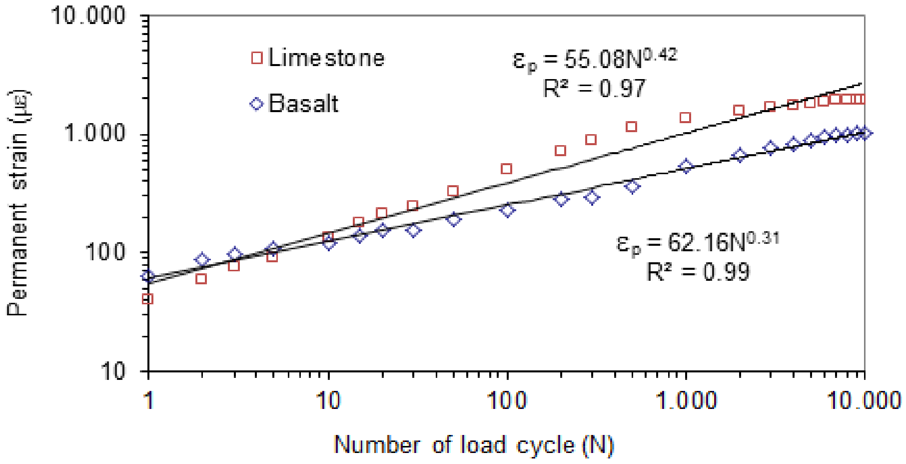


Figure 13 Cumulative permanent axial strain vs. number of load repetitions

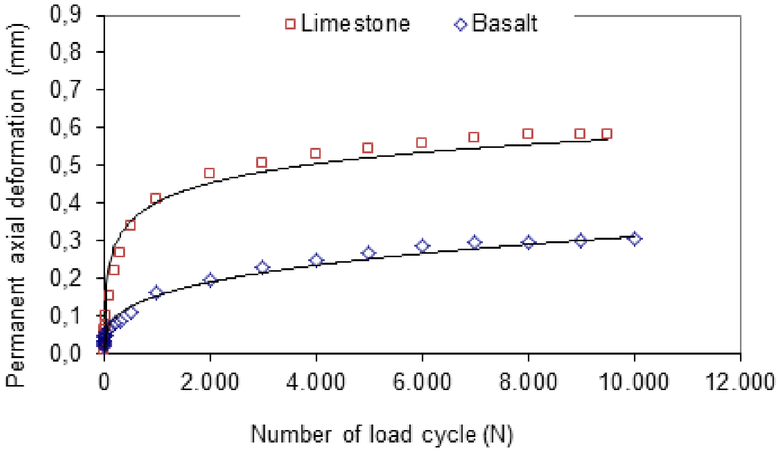


Figure 14 Cumulative permanent axial deformations vs. the number of load repetitions

CONCLUSIONS

Basalt is a stiff, durable, grey and black colored volcanic rock and it is commonly available in nature and spread over different localities in Turkey. In this study, physical and mechanical properties of basalt aggregate examined to use as base and sub-base material in highways.

The physical and mechanical properties of the basalt meet the requirements of the aggregates for granular layers of highway pavements. Besides, basalt aggregate offers advantages compared to limestone aggregates. Basalt has a high abrasion resistance, high durability and high CBR value, on the other hand, the water absorption of basalt aggregate is partially high. The water absorption of the basalt aggregate ranges between 2.0% and 2.06%. The resilient modulus value for the tested materials varied between 113 - 355 mPa for basalt aggregate and 105 – 460 mPa for limestone depending on bulk stress (θ). However, basalt aggregate provides better results than limestone in the LA test, the frost resistance test, aggregate impact value test and the CBR test. The M_r values of limestone slightly higher than basalt aggregate.

Consequently, basalt aggregate have potential to be used as a pavement material in similar applications, where traditional crushed limestone aggregate are used. However at the present time, the use of basalts as aggregate material is limited in Turkey. It is likely to be alternative source for crushed aggregate in the near future.

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REFERENCES

AASHTO T294-94, (1995). “Resilient modulus of unbound granular base/sub-base materials and subgrade soils”. SHRP Protocol P46. Standard specifications for transportation materials and methods of sampling and testing, 17th Edn. Washington, DC.

Allen Cooley, L., Michael S. Huner and Robert H. James, (2002). “Micro-Deval testing of aggregates in the southeast”, NCAT Report 02-09, USA.

Brown SF, Pappin J.W. (1985). “Analysis of pavements with granular bases”. Transportation Research Record. 1022, pp:52-59.

Çopuroğlu, O., Çakır, Ö.A., Broekmans, M.A.T.M., Kühneld, R., (2009). “Mineralogy, geochemistry and expansion testing of an alkali-reactive basalt from western Anatolia, Turkey”, Materials Characterization, Volume 60, Issue 7, pp:756-766.

Fookes, P.G., (1980). “An introduction to the influence of natural aggregates on the performance and durability of concrete”. Quarterly Journal of Engineering Geology, 123, pp:207– 229.

General Directorate of Turkish Highways (GDTH), (2006). “Highway construction specifications”. Ankara, Turkey. General Directorate of Turkish Highways Press No 267.

Goodman, R.E., (1993). “Rock in Engineering Construction”, Engineering Geology. Wiley, New York, p.412.

Ibrahim, A., Faisala, S., Jamil, N. (2009). “Use of basalt in asphalt concrete mixes”, Construction and Building Materials, Volume 23, Issue 1, pp:498-506.

Kandhal, P. S, Parker Jr, F., (1998). “Aggregate tests related to asphalt concrete performance in pavements”, NCHRP Report 405, USA.

Karakuş, A. (2011). “Investigating on possible use of Diyarbakir basalt waste in Stone Mastic Asphalt”, Construction and Building Materials, Volume 25, Issue 8, pp:3502-3507.

Klein, Cornelis and Cornelius S. Hurlbut, Jr., (1985). “Manual of Mineralogy”, Wiley, 20th ed., p 455 ISBN 0-471-80580-7.

Korkanc, M., Tuğrul, A. (2004). “Evaluation of selected basalts from Niğde, Turkey, as source of concrete aggregate”. Engineering Geology 75 pp:291–307.

Le Maitre R.W., (1989). “A classification of Igneous Rocks and Glossary of Terms”, 193 p. Blackwell, Oxford.

Le Maitre, R.W. (2002). “Igneous Rocks, A Classification and Glossary of Terms”., Cambridge University Press, 236 pp. Cambridge.

Lekarp, F., Isacsson, U. and Dawson, A., (2000). “State of the art. I: Resilient response of unbound aggregates”, Journal of Transportation Engineering, Vol.126, No.1, pp:66-75.

Özturan, T. and Çeçen, C., (1997). “Effect of coarse aggregate type on mechanical properties of concretes with different strengths”. Cement and Concrete Research. 27(2), pp:165-170.

Smith, M.R., Collis, L. (Eds.), (2001). “Aggregates: Sand, Gravel and Crushed Rock Aggregates for Construction Purposes”, Geological Society, Engineering Geology Special Publication 17. The Geological Society, London. 339 pp.

Tasong, W.S., Lynsdale, C.J., and Cripps, J.C., (1998). “Aggregate-cement paste interface: II. Influence of aggregate physical properties”. Cement and Concrete Research 28(10), pp:1453-1465.

Tutumluer, E., D.N. Little, and Kim, S.H. (2003). “Validated model for predicting field performance of aggregate base courses”, Transportation Research Record 1837, Washington, D.C., pp:41-49.

Uzan, J. (1985). “Characterization of granular materials”, Transportation Research Record 1022, TRB, National Research Council, Washington D.C., pp:52-59.

Yılmaz, A., Karaşahin M., Çağlar M.F., (2008). “Granüler yol malzemeleri için düşük maliyetli dinamik üç eksenli test cihazı geliştirilmesi”, Süleyman Demirel Üniversitesi, Fen Bilimleri Enst. Dergisi, 12(1), pp:26-34. (in Turkish)

Zaman M, Chen D, Laguros J. (1994). “Resilient moduli of granular materials”. Journal of Transportation Engineering 120(6), pp: 967–988.