THE BALTIC JOURNAL
OF ROAD
AND BRIDGE
ENGINEERING
2022/17(3)

ISSN 1822-427X/eISSN 1822-4288
2022 Volume 17 Issue 3: 104–119
https://doi.org/10.7250/bjrbe.2022-17.571

INFLUENCE OF THE AGGREGATE SHAPE AND RESISTANCE TO FRAGMENTATION ON UNBOUND BASE LAYER RESILIENT MODULUS

VILIUS FILOTENKOVAS[1*], AUDRIUS VAITKUS[2]

[1]*Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania*

[2]*Road Research Institute of Faculty of Environmental Engineering, Vilnius Gediminas Technical University, Linkmenų str. 28, LT-08217 Vilnius, Lithuania*

Received 23 May 2022; accepted 19 August 2022

Abstract. The performance of unbound base materials, exclusively of the upper base layers, besides compaction level and layer thickness, depends on unbound material type, aggregates shape, fine content and mechanical properties of aggregates. The response of the pavement structure to loading is expressed through stress and strain magnitudes, accumulation of which leads to layer permanent deformations. One of the key factors for designing unbound base layers is resilient modulus, which can be found from triaxial tests. The aim of the research is to analyse the effect of the aggregate particle shape, structure and the resistance to crushing properties on resilient modulus of the upper layers of the unbound base layers. The following properties have been determined during the tests: aggregate particle size distribution, particle shape and flakiness, percentage of crushed and broken particle surfaces, density, water absorption, resilient modulus under low stress level loading. According to the performed research with tested aggregate mixtures, it is assumed that most influence on resilient modulus is exerted by aggregate whole granular size distribution,

* Corresponding author. E-mail: vilius.filotenkovas@vilniustech.lt

Audrius VAITKUS (ORCID ID 0000-0001-5103-9747)

water absorption and the largest aggregate particle surface angularity. Resilient modulus in the tested dolomite fraction mixtures differing from 32 mm to 56 mm showed any reasonable difference with mean nominal pressures being higher than 300 kPa.

Keywords: unbound base layer, resilient modulus, aggregate shape, particle resistance to fragmentation, aggregates, triaxial load test.

Introduction

Due to lack of funds or cost savings, the most constructive engineering solutions are not always most effective: worse quality materials are used and the physical and mechanical properties of the layers are not guaranteed. As a result, there is an increasing number of cases where installed structures are damaged before the inter-repair period begins (Filotenkovas & Vaitkus, 2019). Fatigue cracking, rutting, depressions, and frost heaving of flexible pavements can be attributed to poor performance of granular base layer (National Academies of Sciences, Engineering, and Medicine, 2008). Rutting is a gradual accumulation of plastic strain in each layer of a flexible pavement that occurs under repeated axle loading. Rutting can be the result of both densification (decrease in volume) and permanent shear deformation (change in shape without a reduction in volume). Test pits at both the AASHTO and WASHTO Road Tests indicated that rutting in the wheel paths was mainly due to the lateral movement of materials and accumulated permanent deformation (Haynes & Yoder, 1963; Ba, Tinjum & Fall, 2015).

The aggregate shape and type had a significant influence on the resilient modulus. Increasing aggregate particle angularity and roughness, the resilient modulus increases while the Poisson's ratio decreases (Mishra & Tutumluer 2012; Hicks & Monismith, 1971). Although increasing angularity as well as surface texture through aggregate particle contact frictional resistance contributed to a decrease in the dilating effect of the shear stress, which caused a reduction in the resilient modulus (Pan et al., 2006). The aggregate type also had a significant influence on the resilient modulus when other factors were held constant, although influence of shape was not included in the data (Taherkhani, 2015). In addition, layers of unbound aggregates having crushed aggregate particles have consistently proven to be more efficient than those with unbound aggregate particles in terms of providing a stiffer layer for load distribution. However, aggregate particle shape was not found to have a significant effect on the permanent deformation model parameters: test results indicated aggregate angularity to be the most important factor governing aggregate layer behavior (Mishra, Tutumluer & Xiao, 2010). The high content of mineral dust reduced the stiffness of the layer due to low friction between the aggregate particles, but it was found that the resilient modulus of 2–10% mineral dust material changed insignificantly, so the stiffness of the layer depended more on the origin of the materials (Austroads, 2008).

It is found that for flexible pavements the resilient modulus is one of the key factors for testing unbound base layers in order to prevent road failures (Luo et al., 2017). The resilient modulus is a common characteristic of the stiffness of unbound materials, where resilient (recoverable) strain in the material is affected under the deviatoric stress – stiffer material shows less strain under a certain load and thus has a higher resilient modulus (Fladvad & Erlingsson, 2022). The triaxial shear test appeared to be the best candidate for measuring resilient modulus due to its versality, acceptance by many research laboratories, adaptability to different stress states and moisture content and presentation of resilient and permanent deformation.

1. Research subject and methodology

The experiment was performed for aggregate mixtures taken from quarries in Lithuania that are used in unbound base layers. It is a study of the properties of nine aggregate mixtures, their particles and base layers and an analysis of the applicability of the k-θ model. The functioning of the base layer is inseparable not only from the functional properties of pavement layers, but also from the properties of the base layers and their component aggregate particles, so it is important to know pavement deflection and its deviation, layer compaction, aggregate particle shape, resistance to fragmentation and size. Due to the fact that the properties that can influence the resilient modulus are quite wide, the selection of experimental research, modelling and analysis usually uses road construction materials from local quarries for the unbound base layers.

In order to determine the influence of the aggregate particle shape and resistance to fragmentation on the mechanical properties of unbound base layer and on the pavement structures functionality, the geometrical, physical and mechanical properties of the aggregate mixtures and their particles were investigated experimentally. The scheme of the experimental study is presented in Table 1.

Based on the analysis of other scientific studies, it can be stated that knowing the effect of the applied loads on the aggregate mixture expressed by formed deformations, it is possible to calculate resilient modulus of the unbound base layer. For this purpose, k-θ Equation (1), Hicks and Monismith, Yoder, and Witczak, and other similar models are commonly used (Erlingsson, 2007). The k-θ model was chosen considering the novelty, practicality and accuracy of the model.

$$M_R = k_1 \theta^{k_2}, \tag{1}$$

where M_R – resilient modulus, MPa, θ – sum of the principle stresses (average nominal stress), $(\sigma_1 + \sigma_2 + \sigma_3)$: $\sigma_1 + \sigma_2 + \sigma_3$ main distresses; k_1, k_2 – regression coefficients.

The simplicity of this model allows fixing some of the parameters, like moisture and degree of compaction to constants (Rahman & Erlingsson, 2015). To justify the application of this calculation of the resilient modulus by this model, triaxial load tests were performed with the aggregate mixtures of unbound base layers used in Lithuania. The resilient modulus was determined according to EN 13286-7 using the single stage low stress level method under constant lateral and low axial loads and the multi-stage repeated load triaxial test (Erlingsson & Magnusdottir, 2002). In the triaxial test, the resilient modulus is determined at the end of each increase of the load and expressed as a function of the mean nominal pressure (Salour & Erlingsson, 2015). For this particular experiment, deviation from standard procedure was applied: all specimens had diameters of 150 mm.

The aim of the experimental study is to determine the resilient and residual deformations defining the properties of the aggregate mixtures of unbound base layer and the input data necessary for the modelling and functional analysis of the pavement structure.

Table 1. Experimental study scheme for testing aggregate mixtures

Investigation of the shape characteristics of aggregate mixtures	Shape index (EN 933-4:2008) Flakiness index (EN 933-3:2012) Percentage of crushed and broken surfaces (EN 933-5:2002)
Investigation of the structural characteristics of aggregate mixtures	Particle size distribution (EN 933-1:2012) Reference density and water content - Proctor compaction (EN 13286-2:2012) Particle density (EN 1097-6:2013, 7 ch. and annex A.4) Water absorbtion WA (EN 1097-6:2013, 7 ch.)
Investigation of resistance to fragmentation of aggregate mixtures	Determination of resistance to fragmentation LA (EN 1097-2:2020, 5 ch.)
Investigation of resilient modulus of aggregate mixtures	SS LSL MRT – Single stage low stress level resilient modulus test (EN 13286-7:2004, 7.3 ch.) MS RLT – Multistage repeated loading test (EN 13286-7:2004, 8.ch.)

The experiment was performed for two mixtures of crushed gravel, five crushed dolomite mixtures and one granite mixtures produced in five Lithuanian quarries and one crushed dolomite mixture mixed in Vilnius TECH Road Science Laboratory in 2020, for which the granulometric composition was adjusted to be the same as crushed granite mixture. Tests for determining the shape, structural and resistance to fragmentation characteristics were made on five single specimens; for determining resilient modulus, three single specimens were tested. The table of the experimental test objects is presented in Table 2.

Table 2. Tested properties of experimental test objects

Test object No.	1	2	3	4	4*	5	6	7	8
Mineral	Dolomite	Gravel	Dolomite				Granite	Gravel	Dolomite
Fraction	0/32		0/45						0/56
Water absorption, %	1.1	1	1.2	1.3	1.3	2.9	0.2	0.5	1.1
Particle density, Mg/m^3	2.806	2.714	2.779	2.801	2.845	2.763	2.964	2.694	2.789
Percentage of crushed and broken surfaces, %	$C_{100/0}$	$C_{90/3}$	$C_{100/0}$	$C_{100/0}$	$C_{100/0}$	$C_{100/0}$	$C_{100/0}$	$C_{97/1}$	$C_{100/0}$
LA index	LA_{22}	LA_{33}	LA_{25}	LA_{23}	LA_{38}	LA_{38}	LA_{18}	LA_{33}	LA_{23}
Shape index	SI_8	SI_{15}	SI_6	SI_7	SI_7	SI_{12}	SI_{11}	SI_{27}	SI_{10}
Flakiness index	FI_7	FI_{16}	FI_6	FI_6	FI_6	FI_{12}	FI_{10}	FI_{18}	FI_9
Passing through the sieve, mm	**Aggregate particle size distribution**								
0.063	4	6	7	3	6	6	6	6	4
0.5	10	16	13	7	17	13	17	13	8
1	13	20	15	9	20	16	20	16	11
2	18	25	19	12	25	21	25	21	15
4	26	31	26	20	32	31	32	31	22
5.6	31	36	33	27	37	41	37	41	27
8	39	42	39	35	44	52	44	52	35
11.2	47	48	58	45	52	60	52	60	44
16	64	58	65	62	62	69	62	69	55
22.4	77	71	73	76	71	85	71	85	71
31.5	95	88	85	89	82	95	82	95	88
45	100	98	96	96	92	100	92	100	98
56	100	100	100	100	100	100	100	100	100

2. Analysis of the experiment test results

The analysis of the aggregate particle size distribution of the aggregate mixtures showed that most of the aggregate mixtures met the Lithuanian requirements of the aggregate specification (TRA SBR 19), except for the mixtures of dolomite (samples No. 3, 5), gravel (sample No. 2) and granite fraction size 0/45 (sample No. 6) through the sieve with the smallest aggregate particle size of the mixture (0.063 mm) that are 1–2% larger than required (0–5%), as shown in Figure 1. According to the Lithuanian requirements of the installation regulations (ĮT SBR 19), for sieving through the sieve the smallest aggregate particle size of the mixture (0.063 mm) is 0–7%; thus, the mixtures are considered suitable for testing.

The crushed dolomite mixture (sample No. 4*) is a manually sieved crushed dolomite mixture (sample No. 4) so as to correspond to the

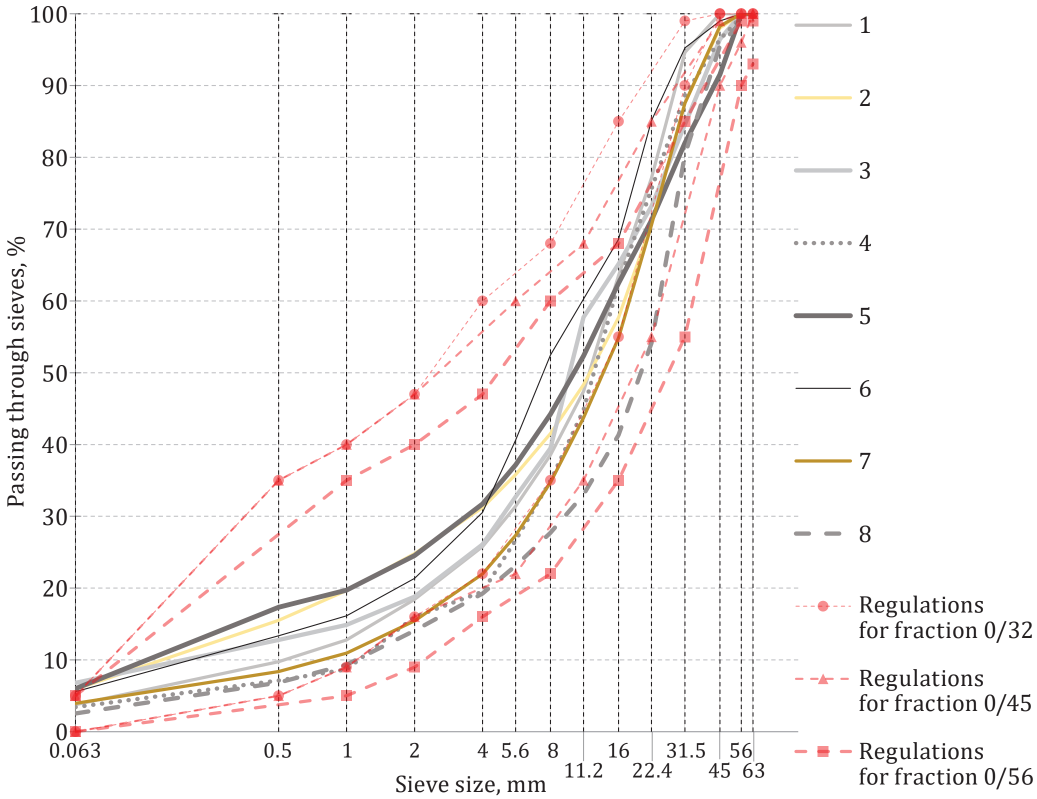

Figure 1. Scheme of aggregate particle size distributions of the studied aggregate mixtures

crushed granite mixture (sample No. 6). As it is the same mixture of dolomite mixture but with a modified aggregate particle size distribution, tests that are not affected by the changed structure of the sample (shape characteristics, water absorption and resistance to fragmentation) were not performed and the properties tested were assigned the same properties as the original dolomite mixture (sample No 4).

Crushed dolomite mixture fraction 0/56 (Sample No. 8) was found to be the largest because the large aggregate particles (4.00–31.5 mm) pass the least (on average 9% smaller than the remaining mixtures). Granite mixture fraction 0/45 (sample 6) was found to be the smallest, as the passing through large sieves (4.00–31.5 mm) is the highest (on average 7% higher than the remaining mixtures). Mixtures of dolomite and gravel mixtures (samples 2 and 5) were also finer, as the fine aggregate particles of 0.063–8.000 mm had larger passing through the sieves than those of the remaining aggregate mixtures (4% higher on average).

The analysis of the shape and flakiness of the aggregate mixtures showed that all the aggregate mixtures met the Lithuanian requirements of the specification (TRA UŽPILDAI 19) (SI_{55} and FI_{50}). The average shape index (SI_{11}) and the average flakiness index between all mixtures (FI_9) are 5 times lower than required in the specification (TRA UŽPILDAI 19). Mixtures of gravel (samples No. 2 and 7) had the highest shape (SI_{15} and SI_{27}, respectively) and flakiness (FI_{16} and FI_{18}, respectively) indices, i.e. had the highest content of non-cubic and flat aggregate particles from the tested mixtures.

Analysing the relative amounts of crushed and broken aggregate particles in the aggregate mixtures, it was found that all aggregate mixtures met the Lithuanian requirements of the specification (TRA UŽPILDAI 19) (C_{c90} and C_{tr3}). All aggregate mixtures were to have more than 90% of the aggregate particles with a partially crushed surface (C_{c90}): 100% of the aggregate particles in the dolomite and crushed granite mixtures were partially crushed, while the aggregate particles in the crushed gravel mixtures (samples 2 and 7) had 90% (C_{c90}) and 97% (C_{c97}) of the partially crushed aggregate particles, respectively; it follows that mixtures of gravel were 10% (C_{r10}) and 3% (C_{r3}) round. Mixtures of dolomite and granite contained, on average, about 88% (C_{tc88}) of fully crushed aggregate particles. Mixtures of gravel (samples No. 2 and 7) contained 54% (C_{tc54}) and 64% (C_{tc64}) of fully crushed aggregate particles, respectively. Mixtures of gravel (samples No. 2 and 7) had 3% (C_{tr3}) and 1% (C_{tr1}) completely round aggregate particles, respectively, and mixtures of crushed granite and dolomite did not contain completely round aggregate particles.

The analysis of the resistance to fragmentation of aggregate mixtures showed that most of the aggregate mixtures met the Lithuanian requirements of the specification (TRA UŽPILDAI 19), except for gravel aggregate mixtures (samples No. 2, 7) and crushed dolomite mixture fraction 0/45 (sample No. 5) with crush resistance values of 3% and 8% above the required value (30%), respectively. The resistance to fragmentation of the remaining dolomite mixtures is on average about 23.2%. The fraction 0/45 (sample No. 6) of the granite mixture had the highest value of resistance to fragmentation (18% higher on average than the remaining mixtures).

For the analysis of resilient modulus k-θ model was applied with average variation value R^2 = 0.89. The analysis of the resilient modulus of the aggregate mixtures showed that the dolomite mixtures (samples No. 1, 4 and 8) had the highest resilient modulus, as shown in Figure 2. The crushed dolomite mixture fraction 0/56 (sample No. 8) showed the highest results of the resilient modulus at an average normal pressure of less than 300 kPa, i.e. under external vertical and horizontal loads. At the lowest average normal pressures (up to 100 kPa), the resilient modulus is on average about 37–45% higher than the remaining aggregate mixtures; between 100 kPa and 300 kPa – 28% higher than the remaining modulus of the aggregate mixtures. The dolomite mixture

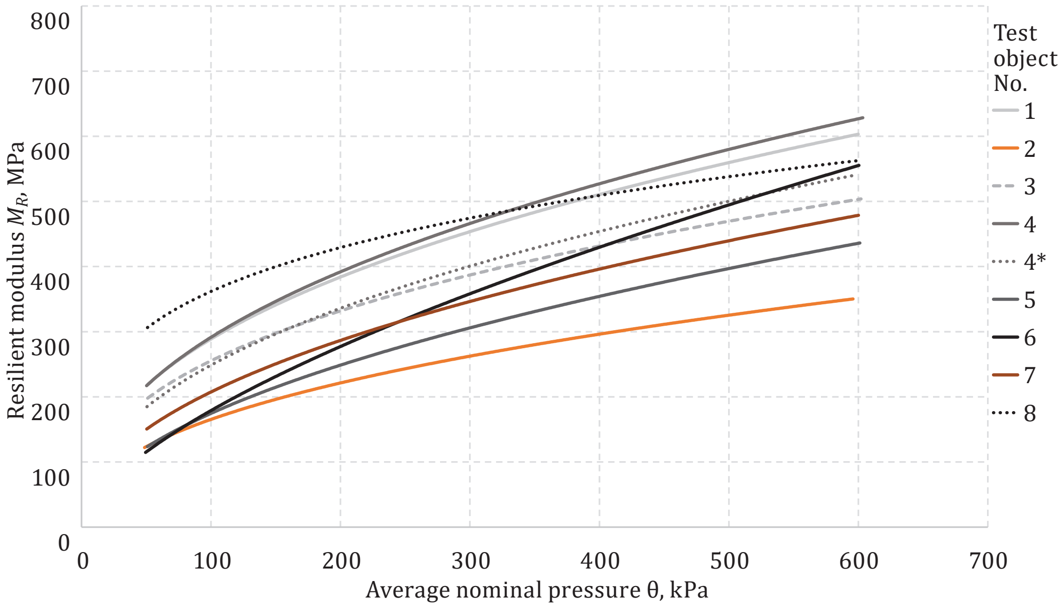

Figure 2. Resilient modulus dependency on aggregate mixtures within different nominal pressure

fraction 0/45 (sample No. 4) showed the highest resilient modulus at an average normal pressure higher than 300 kPa. At maximum average normal pressures (from 100 kPa), the resilient modulus is on average about 19% higher than the modulus of the remaining aggregate mixtures. Crushed dolomite mixture 0/32 (sample No. 1) showed identical results of resilient modulus as crushed dolomite mixture 0/45 (sample No. 4): the values of resilient modulus within the tested average normal stresses were 2% lower than sample No. 4. The crushed gravel mixture fraction 0/45 (sample No. 2) showed the lowest results of the resilient modulus; the resilient modulus is on average about 19% lower than the modulus of the remaining aggregate mixtures. The second lowest results with the resilient modulus were shown by the crushed dolomite mixture fraction 0/45 (sample No. 5) and the crushed gravel mixture fraction 0/45 (sample No. 7).

3. Evaluation of the influence of aggregate shape and resistance to fragmentation on the resilient module of the unbound base layer

The analysis of the granulometric composition of aggregate mixture influence on resilient modulus showed that increasing size of aggregates, i.e. passing through the largest sieves decreases, the resilient modulus increases. The crushed dolomite mixture (sample No. 8), which is found to be the largest and having least passing aggregates through sieves, has on average 22% higher resilient modulus than the remaining aggregate mixtures. This characteristic is apparent at a low mean normal pressure of up to 350 kPa: the sample has on average 30% higher resilient modulus, which is the highest value among the test objects. Meanwhile, the mixture of crushed granite (sample No. 6), which is found to be the finest, has the highest passing through medium and large sieves (from 4 mm to 45 mm), at an average normal pressure of up to 300 kPa has a lower average resilient modulus of 16%.

In view of the aggregates of the same mineralogy, aggregate particle size distributions of dolomite samples No. 1 and No. 3 are similar, although the largest aggregate particle size is different: sample No. 1 has a maximum aggregate particle size of 32 mm, sample No. 3 to 45 mm, but resilient modulus of sample No. 1 is on average 14% higher than that of sample No. 3. In gravel specimen sample No. 2, the aggregate particle size distribution up to aggregate particle size of 16 mm is on average 7% smaller than that of gravel sample No. 7, but resilient modulus of sample No. 7 is on average 24% higher than that of sample No. 2. Aggregate particle size distribution of sample 4 is on average 9% larger than that of sample 4* of the same mixture, but the resilient modulus of sample No. 4 is on average 14% higher than that of sample No. 4*.

In view of the aggregates of different mineralogy, the aggregate particle size distribution of crushed dolomite sample No. 4* and crushed granite sample No. 6 is almost identical, but at normal pressure of up to 350 kPa, resilient modulus of sample No. 4* is on average 15% higher than that of sample No. 6; at normal pressure higher than 350 kPa, resilient modulus of sample No. 4* is on average 5% lower than that of sample No. 6. The aggregate particle size distribution of crushed dolomite sample No. 4 and gravel sample No. 7 is almost identical (mean difference of passing through sieves – 1%), but resilient modulus of sample No. 4 is on average 26% higher than for sample No. 7. Also, the aggregate particle size distribution of dolomite sample No. 5 and gravel sample No. 2 is also almost identical (average difference of passing through sieves up to 16 mm sieve – 2%), but resilient modulus of sample No. 5 is on average 13% higher than in sample No. 2.

No correlation of Proctor density with resilient modulus was observed for tested aggregate mixtures.

Analysing the influence of the density of aggregate particles and the water absorption of the largest aggregate particles on the resilient

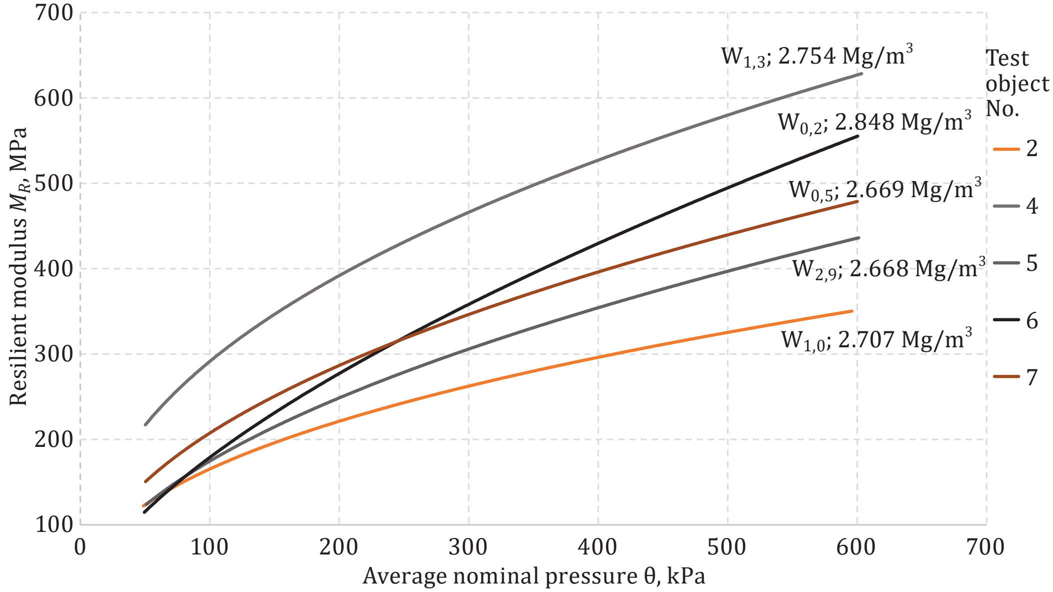

Figure 3. Effect of aggregates density and water absorption on mixture resilient modulus within different average nominal pressure

modulus, it was observed that while the value of water absorption of the same type of aggregate decreased, the resilient modulus increased, as shown in Figure 3. This trend was observed only with materials of the same mineralogy, as the mineral composition of aggregates of different origins differed: the aggregate particle density value of the granite mixture (sample No. 6) was 2.848 Mg/m^3; it follows that there are not many air voids in the aggregate particles into which water can be absorbed, as evidenced by the low water absorption value of 0.2%. Meanwhile, the aggregate particle densities of gravel mixtures (samples 2 and 7) are on average 6% lower; it follows that these aggregate particles are lighter and may have more air voids inside the aggregate particle, indicating an average water absorption value of 0.5%.

The water absorption value of crushed dolomite sample No. 4 is 1.6% lower than that of crushed dolomite sample No. 5, and the resilient modulus is higher by 35%. The water absorption value of gravel specimen sample No. 7 is 0.5% lower than the gravel sample No. 2, and the resilient modulus is higher by 24%.

Analysing the influence of aggregate particle shape and flatness indices on the resilient modulus, it was observed that as the number of flat and cubic aggregate particles in the aggregate mixture decreased, the resilient modulus increased, as shown in Figure 4. Aggregate mixtures with about 6–10% flat aggregate particles and 6–11% non-cubic aggregate particles have on average 30% higher resilient modulus than mixtures with 12–18% flat aggregate particles and 12–27% non-cubic aggregate particles. However, no specific correlations of shape and flatness indices with aggregate resilient modulus at different mean normal pressures were observed. Up to 350 kPa average normal pressure aggregates with higher resilient modulus vary in shape: the maximum values of resilient modulus were found in sample No. 8, having 9% of flat aggregate particles and 10% of non-cubic aggregate particles; samples No. 1 and No. 4 have half the value of resilient modulus of sample No. 8, containing 6% and 7% of flat aggregate particles and 7% and 8% of non-cubic aggregate particles, respectively; sample 6 has the lowest resilient modulus (but the fastest increasing resilient modulus), comprising 10% of flat aggregate particles and 11% of non-cubic aggregate particles. There is a tendency of shape indicators from 350 kPa average normal pressure aggregate mixtures with higher values of resilient modulus – shape and flatness indices decrease. Thus, we can conclude that with increasing average normal pressure (from 350 kPa), the shape and flatness indices have a greater influence on the resilient modulus.

Depending on the amount of crushed and broken aggregate particles in the aggregate mixture, two mixtures were found to have less than

100% broken aggregate particles and more than 0% completely round aggregate particles – crushed gravel samples No. 2 and No. 7. Although sample No. 7 contains 2% more flat and 12% non-cubic aggregate particles than sample No. 2, the resilient modulus is on average 24% higher. This shows the influence of the amount of crushed and broken aggregate particles in the crushed gravel mixtures: sample No. 7 contains 7% more broken surface on aggregate particles and 2% less completely round aggregate particles than sample No. 2. In terms of different sizes of aggregate particles, sample No. 7 contains 44 % more broken surface on aggregate particles (size 32/45) and 17 % less completely round aggregate particles (size 32/45) than sample No. 2; all other aggregate particle fraction crushed and broken surface differs around 2%. It can be concluded that the index C of the largest aggregate particles has a greater effect on the resilient modulus than the shape and plane indices in aggregate mixtures in which unbroken natural gravel may be used.

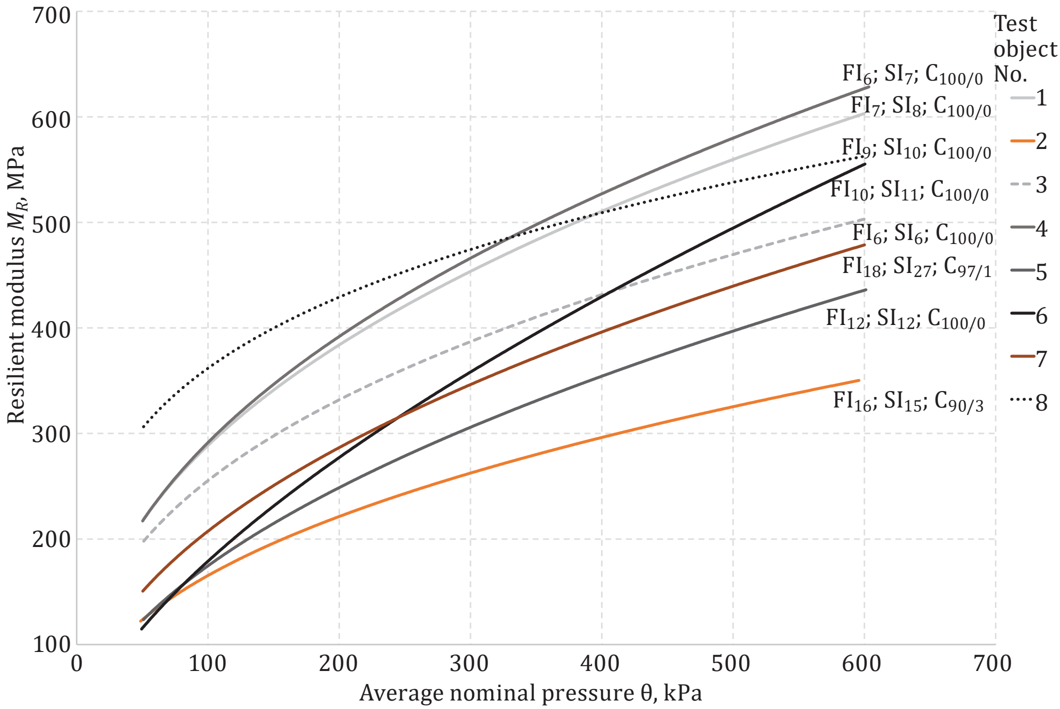

Figure 4. Effect of the aggregate flakiness, shape indices and relative amount of crushed and broken aggregate particles on resilient modulus within different average nominal pressure

Analysing the influence of the resistance to fragmentation of aggregate resilient modulus, it was found that the index of resistance to fragmentation to resilient modulus has no clear trends, as seen in Figure 5. The specimens with the highest resistance to fragmentation show higher values of resilient modulus, but do not correlate with each other, as the crushed dolomite specimen No. 4 with 21% less resistance to fragmentation than granite specimen No. 6 has the values of the resilient modules that are 20% higher on average. Meanwhile, the specimens with the lowest resistance to fragmentation show lower values of resilient modulus, but also do not correlate with each other, as gravel specimen No. 2, having a 14% higher resistance to fragmentation than dolomite specimen No. 5, the value of the resilient modulus is 13% lower on average. Given the same type of material but with different values of resistance to fragmentation, the trend is also not observed: in crushed dolomite sample No. 4, having a 40% higher resistance to crushing than dolomite specimen No. 5, the values of the resilient modules are 35% higher on average. Meanwhile, in gravel samples No. 2 and No. 7, having the same resistance to crushing, the values of the resilient modules differ on average by 24%.

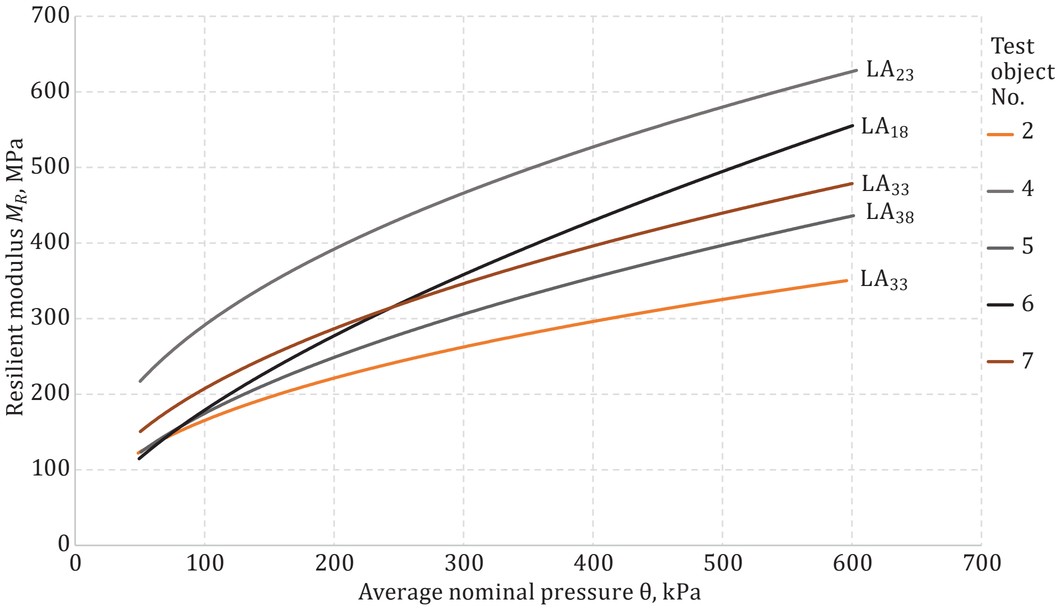

Figure 5. Effect of the aggregate resistance to fragmentation on resilient modulus within different average nominal pressure

Conclusions

1. Different mineralogy aggregates affect resilient modulus of aggregates mixture: dolomite showed the highest resilient modulus with lower mean nominal pressure (up to 350 kPa), but with higher nominal pressure, granite and dolomite resilient modulus values become identical. The highest values of the resilient modulus (averaging by 37% higher values than other mixtures) at the lowest average normal pressures (up to 210 kPa) were shown by the crushed dolomite mixture fraction 0/56 – aggregate mixture with the largest aggregate particles tested; with increasing average normal pressure, crushed dolomite mixtures with similar values of shape and resistance to fragmentation, but smaller highest aggregate particle size showed the same values of resilient modulus. The crushed granite mixture showed the largest change with increasing average normal pressure: with increasing load, the resilient modulus of the crushed granite mixture increased the most. Gravel showed the lowest resilient modulus results, 19% lower resilient modulus values compared to the tested dolomite and granite mixtures.
2. Aggregate particle size distribution does the most affect resilient modulus: aggregate mixtures, passing through medium and large 4–45 mm sieves, showed lower resilient modulus results than mixtures having higher passing through the mentioned sieves. Any reasonable differences were not observed in tested dolomite mixtures resilience modulus depending on mixture fraction varying from 32 mm to 56 mm with mean nominal pressure being higher than 300 kPa.
3. While no correlation of Proctor density with resilient modulus was observed for tested aggregate mixtures, the analysis of density of aggregate particles and the water absorption of the largest aggregate particles on the resilient modulus showed that while the value of water absorption of the same type of aggregate decreased by around 0.5–1.6%, the resilient modulus increased by around 24–35%.
4. With higher average nominal pressure (from 350 kPa), the shape and flatness indices have a greater influence on the resilient modulus – lower values of shape and flatness indices led to higher resilient modulus values. The same type gravels with the biggest difference in crushed and broken aggregate particles of size 32/45 showed that having 44% more broken surface and 17% less completely round aggregate particles produced 24% higher resilient modulus.
5. Index of resistance to fragmentation by Los Angeles method to resilient modulus has no clear trends to the tested aggregates.

6. According to the performed research with the tested aggregate mixtures, it is assumed that most influence on resilient modulus is exerted by aggregate whole granular size distribution, water absorption and the largest aggregate particle surface angularity; and the least influence is exerted by Proctor density and optimal water content values. It is also necessary to assess the impact of these parameters on permanent deformation of the unbound base layer, which is planned to be performed in the next phase of research.

REFERENCES

Austroads (2008). Guide to Pavement Technology / Part 4A: Granular Base and Subbase Materials.

Ba, M., Tinjum, J., & Fall, M. (2015). Prediction of permanent deformation model parameters of unbound base course aggregates under repeated loading. *Road Materials and Pavement Design*, *16*(4), 854–869. https://doi.org/10.1080/14680629.2015.1063534

Erlingsson, S. (2007). On Forecasting the Resilient Modulus from the CBR Value of Granular Bases. *Road Materials and Pavement Design*, *8*(4), 783–797. https://doi.org/10.1080/14680629.2007.9690099

Erlingsson, S., & Magnusdottir, B. (2002). Dynamic Triaxial Testing of Unbound Granular Base Course Materials. In *Bearing Capacity of Roads, Railways and Airfields.* CRC Press. https://doi.org/10.1201/9781003078821-21

Filotenkovas, V., & Vaitkus, A. (2019). Effect of compaction and hydraulic gradient on subbase layer permeability. *Coatings*, *9*(10), 0641. https://doi.org/10.3390/coatings9100641

Fladvad, M., & Erlingsson, S. (2022). Modelling the response of large-size subbase materials tested under varying moisture conditions in a heavy vehicle simulator. *Road Materials and Pavement Design*, *23*(5), 1107–1128. https://doi.org/10.1080/14680629.2021.1883462

Haynes, J. H., & Yoder, E. J. (1963). Effects of Repeated Loading on Gravel and Crushed Stone Base Course Materials Used in the AASHO Road Test. Publication FHWA/IN/JHRP-63/04. Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1963. https://doi.org/10.5703/1288284313622

Hicks, R. G., & Monismith, C. L. (1971). Factors Influencing the Resilient Properties of Granular Materials. *Highway Research Record*, *345*, 15–31.

Luo, X., Gu, F., Zhang, Y., Lytton, R. L., & Zollinger, D. (2017). Mechanistic-Empirical Models for Better Consideration of Subgrade and Unbound Layers Influence on Pavement Performance. *Transportation Geotechnics*, *13*, 52–68. https://doi.org/10.1016/j.trgeo.2017.06.002

Mishra, D., Tutumluer, E., & Xiao, Y. (2010). Particle Shape, Type, and Amount of Fines and Moisture Affecting Resilient Modulus Behavior of Unbound Aggregates. *GeoShanghai International Conference 2010, Paving Materials and Pavement Analysis*, 279–287. https://doi.org/10.1061/41104(377)34

Mishra, D., & Tutumluer, E. (2012). Aggregate Physical Properties Affecting Modulus and Deformation Characteristics of Unsurfaced Pavements. *Journal of Materials in Civil Engineering*, *24*(9), 1144–1152. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000498

National Academies of Sciences, Engineering, and Medicine (2008). Performance-Related Tests of Recycled Aggregates for Use in Unbound Pavement Layers. The National Academies Press. https://doi.org/10.17226/23108

Pan, T., Tutumuer, E., & Anochie-Boateng, J. (2006). Aggregate Morphology Affecting Resilient Behavior of Unbound Granular Materials. *Transportation Research Record: Journal of the Transportation Research Board*, *1952*(1), 12–20. https://doi.org/10.1177/0361198106195200102

Rahman, M. S., & Erlingsson, S. (2015). A model for predicting permanent deformation of unbound granular materials. *Road Materials and Pavement Design*, *16*(3), 653–673. https://doi.org/10.1080/14680629.2015.1026382

Salour, F., & Erlingsson, S. (2015). Resilient modulus modelling of unsaturated subgrade soils: laboratory investigation of silty sand subgrade. *Road Materials and Pavement Design*, *16*(3), 553–568. https://doi.org/10.1080/14680629.2015.1021107

Taherkhani, H. (2015). An Investigation on the Effects of Aggregates Properties on the Performance of Unbound Aggregate Base Layer. *International Journal of Transportation Engineering*, *3*, 151–164.