Using Hungarian andesite as a coarse aggregate for concrete

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Abstract

The study focuses on producing a new structural concrete utilising andesite aggregate as an igneous rock extracted from Hungary. Thus, the andesite coarse aggregates' physical properties, such as density, moisture content, water absorption and thermogravimetric properties, were tested. Two concrete mixtures were prepared, one using the quartz aggregate as a reference mix and one with 100% replacement of coarse aggregate by andesite aggregates for estimating the concrete proportions and the mechanical properties for long-term up to 240 days. Physical and mechanical tests showed that andesite extracted from Hungarian mountains could be a useful coarse aggregate for structural concrete with better behaviour than the normal quartz aggregate commonly used.

Keywords: andesite, coarse aggregate, compressive strength, concrete, flexural strength, quartz, shear strength

Kulcsszavak: adalékanyag, andezit, hajlítószilárdság, kvarckavics, nyomószilárdság, nyírás, szerkezeti beton

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1. Introduction

Millions of tons of aggregate are used each year in construction worldwide. The essential qualities of these aggregates are mechanical strength, service life, safety, and environmental aspects in construction; one of the most important places to provide these aggregates is natural stone products. Natural stones are essential building materials, as they are used as dimension stones and aggregates [1]. Their mechanical properties control their applicability. Volcanic rocks such as basalt and andesite are the most common types found in Hungary, and are utilised in the construction industry as aggregates [2-4], andesite, as one of the most common igneous rock types in Hungary, is often used as aggregate in road construction and railway constructions [2, 5, 6, 7]; or as armor stone in hydraulic engineering [8, 9]. In comparison, sedimentary rocks in Hungary are mainly used as building or decorative stones and sometimes as a concrete aggregate for small buildings [10].

Among the volcanic rocks, andesite is one of the most common volcanic rocks of the Carpathian Basin, which got its name from the American Andes mountains. Andesite, which comes in shades of brown, grey, and black, and their transitions, is typically composed of plagioclase feldspar and various coloured minerals. They show an extraordinary similarity with dacites, which is why in each case the site or the mixed analysis of the samples decides what their silicon content is and in which category they can be classified. Andesite is commonly found in Hungary, particularly in the Börzsöny, Cserhát, and Mátra mountain ranges and it is easily accessible due to its proximity to the surface. [10], the andesite used in this study was extracted from Kisnána (Mátra). However, different weathering categories ranging from fresh to residual soil can be observed within the andesite [11]. The favourable properties of andesite (high uniaxial compressive strength and resistance to abrasion) make it suitable for road and railway construction as pavement production. Andesite is a fine-grained volcanic rock with about (53–63%) silica-containing, grey-black colour. It has a porphyritic texture and is composed of plagioclase and pyroxene microliths (clinopyroxene and orthopyroxene), feldspar, pyroxene, and biotite phenocrysts in a glass matrix, and small amounts of magnetite minerals. Andesite's porosity ranges between 10% and 25%. Therefore, andesites used in indoor and outdoor spaces are exposed to a variety of physical and chemical factors, such as cold, heat, moisture, and household chemicals, as well as a number of impact-induced wear factors. Andesite materials show resistance to environmental factors to which they may be exposed [12, 13].

The andesite aggregate is nothing new. It has long been found to have favourable tensile and compressive strengths due to its higher modulus of elasticity and different shape [14]. However, the steady decrease in the water-cement ratio changes the saturation of concretes and is not typical when testing concretes older than three or six months. Transport is an important factor for economic and environmental reasons, and local materials should be known. Stone tests are available, but for structural concretes, there are often other considerations [10, 15], e.g. wear resistance is not important, and the conditions of placing are different.The purpose of this study was to investigate the potential use of andesite aggregate as a structural concrete aggregate. To accomplish this, laboratory experiments were conducted to evaluate the mechanical properties of andesite aggregate concrete and quartz aggregate concrete as a reference materials. Results showed that aggregate type significantly influences concrete properties, which is not always considered in conventional views and prediction models.

2. Experimental details

2.1 Materials

Two types of coarse aggregates with a particle size of 4-8 mm were utilised in the investigation mix designs. The coarse aggregate types used were normal quartz aggregate (*Fig. 1*) and crushed andesite aggregate (*Fig. 2*). The coarse aggregates accounted for 55% of the total aggregate content in the mixture. A fine aggregate, normal quartz sand with a particle size of 0-4 mm (*Fig. 3*), was also utilised and accounted for 45% of the total aggregate content. Ordinary Portland cement 42.5 N in accordance with EN 197-1, 2012 [16] was used as the binder and superplasticiser (Master Glenium C300) at a dosage of 0.7% by weight of cement used in the mixture.

Fig. 1 Used quartz gravel 4/8 mm particle size
1. ábra Az alkalmazott kvarckavics adalékanyag 4/8-as frakció

Fig. 2 Used crushed andesite aggregate 4/8 mm particle size
2. ábra Az alkalmazott andezitzúzalék 4/8-as frakció

Fig. 3 Used quartz sand 0-4 mm particle size
3. ábra Az alkalmazott kvarchomok 0/4-es frakció

2.2 Methodology

The physical properties of the aggregates were tested to determine the main aggregate characteristics as the particle size, density and water absorption to ensure proper mixes of the concrete, In order to determine the properties of concrete made by andesite aggregates, two concrete mixes were prepared. The volume content of the used materials in each mixture was kept the same, as shown in *Table 1*. To investigate the influence of aggregate types and determine the exact effect of this use, so volumes were included in each density, and the specimen's density was changed depending on the aggregate density.

After preparing the concrete mixtures, all specimens were cured for 7 days under water and then stored in the laboratory at ambient temperature until the age of 28, 120 and 240 days. Uniaxial compressive strength using 100 mm cubes, flexural tensile strength using 70 mm x 70 mm x 250 mm prismatic shapes, and Push off model with 100 mm diameter x 150 mm height cylinders specimens were used for shear strength tests made to determine the concrete characteristics and classification.

Material	Component materials in 1 m³ batch (kg/m³)	
	Mix Q	Mix An
Cement	450	450
Water (w/c: 0.38)	171	171
Fine aggregate (0/4)	799	799
Andesite aggregate (4/8)	-	962
Quartz aggregate (4/8)	958	-
Superplasticiser (0.75%)	3.37	3.37

Table 1 Concrete mix proportions
1. táblázat Az alkalmazott betonösszetételek

3. Physical properties testing

3.1 Particle size distribution

Andesite and quartz aggregates were sieved and divided into three fractions (0/4, 4/8, and 8/11) using a sieve series according to EN 933-1 [17]. The faction with a sieved size 4/8 mm is used as coarse aggregates in both andesite and quartz aggregates, and the sieved size of less than 4 mm is used as fine aggregate in the case of river quartz sand.

3.2 Particle density

The particle density of aggregates was determined with the Pycnometer device according to EN 1097–6:2013 [18], employing the water displacement method to measure volume accurately. Three consecutive volume measurements were performed for each type of aggregate to obtain an average particle density value; the value for each aggregate type are mentioned in *Table 2*.

Aggregate	Particle density kg/m³
Quartz aggregate 0/4	2640
Quartz aggregate 4/8	2590
Crushed andesite aggregate 4/8	2600

Table 2 Particle density test results of aggregates
2. táblázat Az adalékanyagok testsűrűsége

3.3 Moisture content and absorption

Aggregates (fine and coarse) were dried in an electric oven at 105 °C, to determine the moisture content value for each type of aggregate according to EN 1097–5:2008 [19]; the moisture content test for aggregates was carried out under the same environment and same conditions; moisture content results showed on *Table 3*.

Aggregate	Moisture content wt%	Water absorption wt%
Quartz aggregate 0/4	1.01	1.98
Quartz aggregate 4/8	1.52	1.10
Crushed andesite aggregate 4/8	3.53	1.27

Table 3 Moisture content and water absorption test results of aggregates
3. táblázat Az adalékanyagok nedveségtartalma és vízfelvétele

Water absorption of aggregates was determined as well, according to EN 1097–6:2013 [18], by measuring the quantity of water present in each aggregate at saturated surface dry state (SSD) and the results of water absorption shown in *Table 3*.

3.4 Derivatographic measurement

The derivatograph simultaneously produces a thermogravimetric (TG), derivative thermogravimetric (DTG) and a differential thermoanalytical (DTA) signal. A small sample was ground to powder and then heated in the device's furnace at a constant rate up to 1000 °C [20]. The test parameters used are: aluminium oxide as a reference substance, the test carried out with temperatures ranging from 20 to 1000 °C with 10 °C/min heating rate and 50 mg TG sensitivity with corundum crucible, under the atmospheric pressure, test results were analysed with the WINDER software. The derivatograms of the andesite and the quartz sample are shown in *Fig. 4* and *Fig. 5*. The study analysed the thermal behaviour of the quartz and andesite samples using a derivatograph. The quartz sample did not exhibit any changes during the test and was not analysed further. However, it was used as a reference for comparison with the andesite sample. The andesite sample showed a peak value (N) between 20 and 120°C, which is indicative of the evaporation of water from the pores. Based on the results, the andesite only loses water in the measured temperature range. Otherwise, its chemical composition is not affected by heat [21].

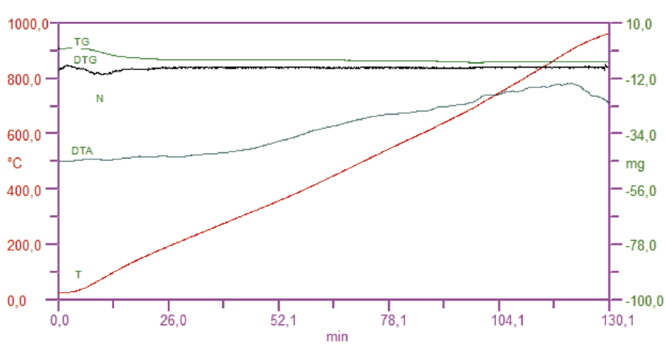

Fig. 4 Derivatogram of the andesite aggregate [18]
4. ábra Az andezit derivatogramja [18]

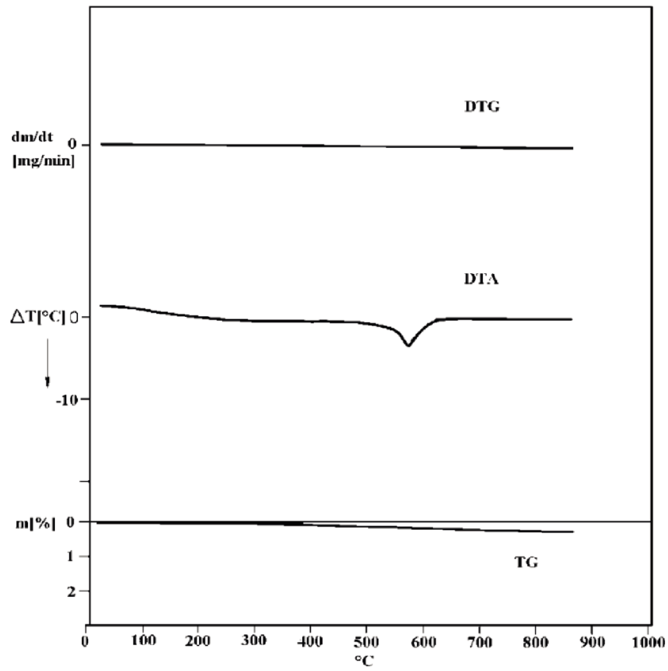

Fig. 5 Derivatogram of quartz aggregate [19]
5. ábra A kvarckavics derivatogramja [19]

4. Results and discussion

4.1 Compressive strength test

The uniaxial compressive strength test of concrete, according to EN 12390-3:2009 [22] for cubes with 100 mm x 100 mm x 100 mm, was carried out at 28 days, 120 days and 240 days age of the specimen, three cubes were tested at each time. *Table 4* and *Fig. 6* present the results of compressive strength tests on concrete made with quartz aggregate (Mix Q) and andesite aggregate (Mix An). The data shows that compressive strength increases with the age of the specimen. Notably, there was a significant increase in compressive strength from 120 to 240 days in the andesite aggregate concrete. On the other hand, the increase in compressive strength from 28 to 120 days in the quartz aggregate concrete was more significant. There can be several scientific reasons why the increase in compressive strength from 28 to 120 days in the quartz aggregate concrete (Mix Q) was more significant than the increase from 120 to 240 days in the andesite aggregate concrete (Mix An). One possible reason is that the increase in compressive strength from 28 to 120 days is more significant for the quartz aggregate concrete due to the rapid hydration of cement, which results in the formation of additional calcium-silicate-hydrate (C-S-H) gel and an increase in the density of the cement paste [26]. This effect is more pronounced at early ages when the hydration reactions are still active. Additionally, the specific properties of the quartz aggregate, such as its mineralogy, may also have played a role in the observed difference in the rate of increase of compressive strength with time. Quartz aggregate may have higher pozzolanic activity and react with the cement paste to form additional C-S-H gel and increase compressive strength at early ages [27, 28].

Age (day)	Concrete type	Average compressive strength (MPa)	Standard deviation (σ)	COV%
28	Mix Q	67.56	2.62	4
28	Mix An	85.81	3.82	4
120	Mix Q	79.12	1.43	2
120	Mix An	86.82	2.67	3
240	Mix Q	80.60	1.41	2
240	Mix An	93.80	0.17	0

Table 4 Compressive strength test results
4. táblázat Nyomószilárdság vizsgálati eredmények

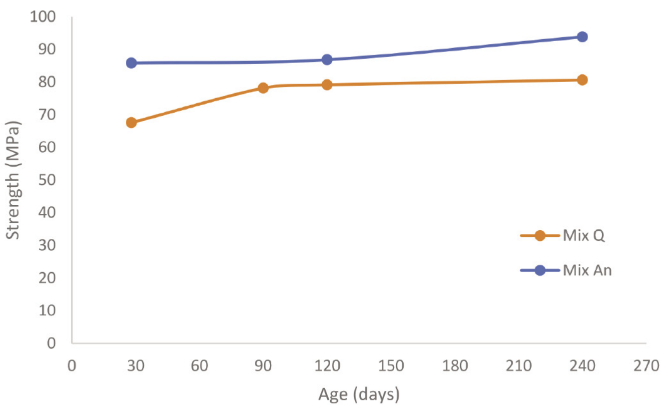

Fig. 6 Compressive strength results
6. ábra Nyomószilárdsági eredmények

4.2 Flexural strength test

The flexural tensile strength test was performed according to EN 12390-5 [23] using 3-point loading bending flexure machine *Fig. 7*, with a constant loading rate 80 N/s, for prisms with 70 mm x 70 mm x 250 mm, at ages 28 days, 120 days and 240 days for three specimens each time.

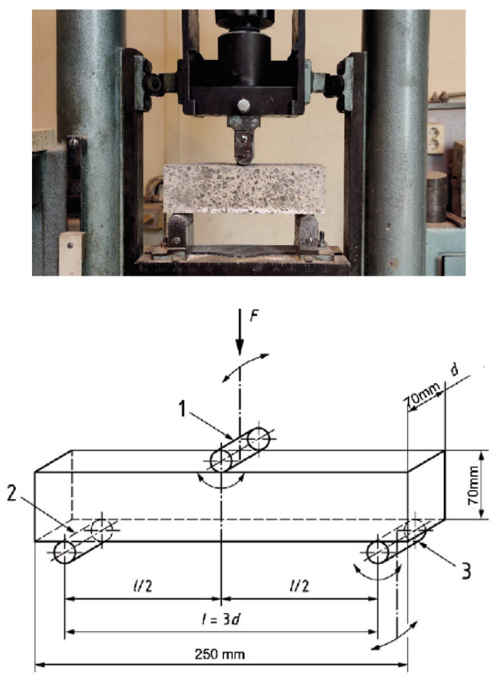

Fig. 7 Three-point bending test [22]
7. ábra A központos hajlító vizsgálat elrendezése [22]

The results of flexural tensile strength tests showed almost similar behaviour between the specimen made by quartz aggregates and the andesite aggregate with a difference of about 20% higher for concrete (Mix An) as shown in *Table 5* and *Fig. 8*. The change in tensile strength for both (Mix-Q) and (Mix-An) with the specimen age are not noticeable.

Age (day)	Concrete type	Average tensile strength (MPa)	Standard deviation (σ)	COV%
28	Mix Q	8.4	0.06	1
28	Mix An	10.2	0.17	2
120	Mix Q	8.8	0.15	2
120	Mix An	10.9	0.29	3
240	Mix Q	8.8	0.20	2
240	Mix An	11.0	0.06	1

Table 5 Flexural tensile strength test results
5. táblázat Hajlítószilárdság vizsgálati eredmények

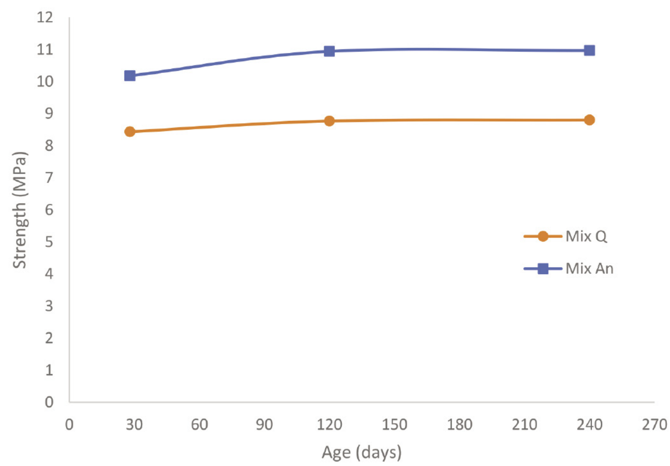

Fig. 8 Flexural tensile strength results
8. ábra Hajlító-húzó szilárdsági eredmények

The andesite aggregate's lower porosity than the quartz aggregate resulted in a higher modulus of elasticity and compressive strength of the concrete, which translates to a higher flexural tensile strength. Moreover, andesite aggregate contains high amounts of silica, alumina, and iron oxide [29]; these elements may react with the cement paste and form additional C-S-H gel, which can increase the flexural tensile strength.

4.3 Shear strength test

The shear strength test was performed using the push-off model. The cylindrical concrete specimens with 100 mm diameter and 200 mm height, the detailed dimension and loading arrangement of the loading specimens were drawn in *Fig. 9*, tested in compression with a loading rate 10 kN/minute. Shear strength test results (*Table 6* and *Fig. 10*) showes that in case of andesite concrete (Mix An) the strength is linearly increased with the concrete age increase, while in case of quartz concrete (Mix Q) the strength increased up to 120 days age, then it does not change until 240 days.

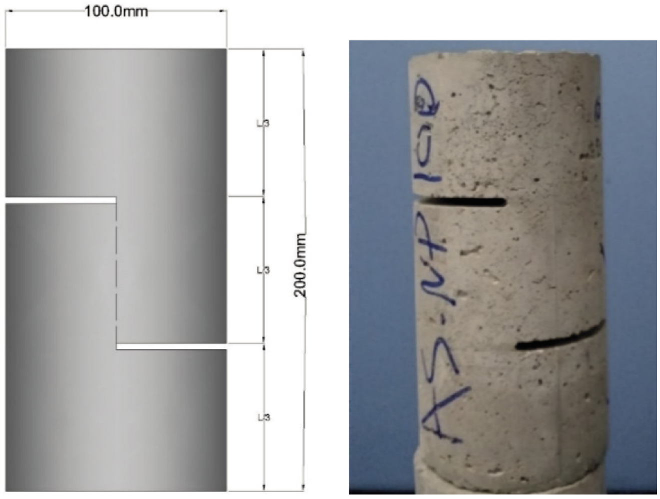

Fig. 9 Push-off specimen dimensions [23]
9. ábra Nyíró (push-off) vizsgálati elrendezés [23]

Age (days)	Concrete type	Average shear strength (MPa)	Standard deviation (σ)	COV%
28	Mix Q	10.3	0.47	5
28	Mix An	10.4	0.41	4
120	Mix Q	10.9	0.60	6
120	Mix An	11.3	0.31	3
240	Mix Q	10.9	0.12	1
240	Mix An	12.2	0.31	2

Table 6 Shear strength results
6. táblázat Nyírószilárdság vizsgálati eredmények

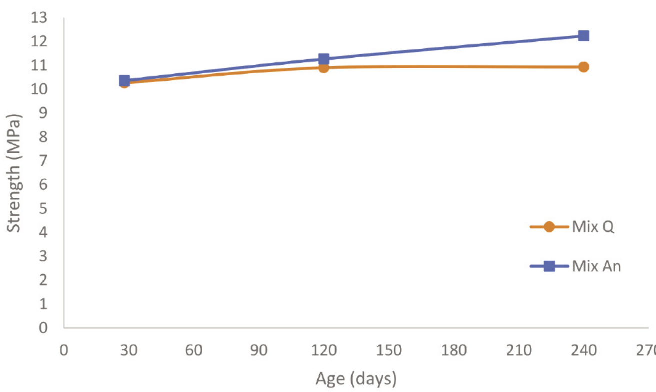

Fig. 10 Shear strength results
10. ábra Nyírószilárdsági eredmények

5. Conclusions

The objective of this study was to evaluate the potential of andesite aggregate as a structural concrete aggregate by examining its mechanical properties over a period of 240 days. The following conclusions are drawn based on the test results and the analysis:

Andesite as one of the most common volcanic rocks used in road construction, and it would be a good aggregate to use as an aggregate for structural concrete.

The particle density results showed almost similar densities for both quartz and andesite aggregates. It does not change the density of concrete to such an extent that it needs to be taken in case of static calculation.

Quartz aggregates were not shown any change during the derivatograph test, but in the case of andesite aggregates, the peak value (N) can be seen from 20 °C and 120 °C, according to the evaporation of water from the pores.

The results of the study indicate that andesite aggregate can be used as a structural concrete aggregate, as it demonstrated similar or better mechanical properties compared to concrete made with quartz aggregate.

Even though both particle densities were the same, the concrete made with andesite aggregates showed higher characteristic compressive strength by about 27% at age 28 days, 10% at age 120 days and 16% at age 240 days.

The compressive strength of concrete made with andesite aggregate showed a significant increase from 120 to 240 days, while the increase in compressive strength for concrete made with quartz aggregate was more significant at early ages.

The flexural tensile strength for concrete (Mix Q) and (Mix An) showed almost similar behaviour by specimen age, with about 20 to 24% increase in strength for concrete made with andesite aggregate (Mix An) compared with (Mix Q) made with quartz aggregate.

Shear strength behaviour in case of (Mix An) concrete increased linearly with the age , while in case of quartz concrete (Mix Q) the strength increase only noticed up to 120 days age.

The pozzolanic activity and mineralogy of the aggregate played an important role in the mechanical properties of the concrete, and further research is needed to investigate these aspects.

Our tests showed that the replacement of quartz gravel with the tested andesite in building construction structures improves the concrete mechanical properties.

This can already be seen in the standard 28 days test, but the trend is the same or improving up to 240 days age.

This is the basis for the fact that it is worth carrying out detailed durability and fire resistance tests, which is important in the case of high-rise buildings and rarely tested for andesite, because the traffic construction does not required it.

References

[1] Přikryl, R. (2017). Constructional geomaterials: versatile earth resources in the service of humankind introduction to the thematic set of papers on: challenges to supply and quality of geomaterials used in construction. Bulletin of Engineering Geology and the Environment, 76(1), 1-9. https://doi.org/10.1007/s10064-016-0985-0

[2] Gálos, M., & Kárpáti, L. (2007). Testing of Hungarian aggregates for railway ballast according to MSZ EN 13450: 2003. Central European Geology, 50(4), 353-361. https://doi.org/10.1556/CEuGeol.50.2007.4.5

[3] Papp Lajos, Puskásné Hőgyes Irén, Rózsa Péter (1985) Sárospatak környéki andezittestek kőbányászati hasznosításának lehetőségei – Utilisation Possibilities of Andesites of Sárospatak from the point of Quarrying Építőanyag 1985/3.

[4] Jugovics Lajos (1969) A Karancs hegy andezitjének kőzettani-kőzetmechanikai vizsgálata – A Petrographical – Rock Mechanical Study of the Karancs Andesite Építőanyag 1969/9.

[5] Balázs György, Erdélyi Attila, Horváth Albert (1967) Visegrád környéki andezitek és dácitok tartóssági vizsgálata vízépítési beton-adalékanyag szempontjából – Durability of Andesites and Dacites from the Visegrad Region as Possible Aggregates for Hydrotechnical Concrete Építőanyag 1967/4.

[6] Czinder, B., Török, Á. Strength and abrasive properties of andesite: relationships between strength parameters measured on cylindrical test specimens and micro-Deval values—a tool for durability assessment. Bull Eng Geol Environ 80, 8871–8889 (2021). https://doi.org/10.1007/s10064-020-01983-9

[7] Klespitz J. (2012) Quarry-geological observations in the Komló andesite pit. (Bányaföldtani tapasztalatok a komlói andezitbányában.). Epitoanyag-Journal of Silicate Based & Composite Materials 64:18–21. https://doi.org/10.14382/epitoanyag-jsbcm.2012.3

[8] Ferestade, I., Tehrani, P. H., & Heidary, R. (2017). Fracture toughness estimation of ballast stone used in Iranian railway. Journal of Rock Mechanics and Geotechnical Engineering, 9(5), 892-899. https://doi.org/10.1016/j.jrmge.2017.03.017

[9] Ertas, B., & Topal, T. (2008). Quality and durability assessments of the armourstones for two rubble mound breakwaters (Mersin, Turkey). Environmental geology, 53(6), 1235-1247. https://doi.org/10.1007/s00254-007-0712-z

[10] Török, Á. (2015). Los Angeles and Micro-Deval values of volcanic rocks and their use as aggregates, examples from Hungary. In Engineering Geology for Society and Territory-Volume 5 (pp. 115-118). Springer, Cham. https://doi.org/10.1007/978-3-319-09048-1_23

[11] Orhan, M., Işık, N. S., Topal, T. & Özer, M. (2006). Effect of weathering on the geomechanical properties of andesite, Ankara–Turkey. Environmental Geology, 50(1), 85-100. https://doi.org/10.1007/s00254-006-0189-1

[12] Sariisik, A., & Sariisik, G. (2011). Environmental interaction properties of marble used in the restoration of historical monuments (Dalyan-Kaunos). Ekoloji, 79, 12-20. https://doi.org/10.5053/ekoloji.2011.792

[13] Uzun, İ., & Terzi, S. (2012). Evaluation of andesite waste as mineral filler in asphaltic concrete mixture. Construction and Building Materials, 31, 284-288. https://doi.org/10.1016/j.conbuildmat.2011.12.093

[14] Alexander,* Mark G.** & Ballim, Y. (1986). The concrete-making properties of andesite aggregates. Civil Engineering= Siviele Ingenieurswese, 1986(2), 49-57.

[15] Czinder, B., & Török, Á. (2021). Strength and abrasive properties of andesite: Relationships between strength parameters measured on cylindrical test specimens and micro-Deval values—a tool for durability assessment. Bulletin of Engineering Geology and the Environment, 80, 8871-8889. https://doi.org/10.1007/s10064-020-01983-9

[16] EN, 197-1: 2011Cement–Part 1: Composition, specifications and conformity criteria for common cements. London: European Committee For Standardisation.

[17] EN, 933-1: 2012 Tests for Geometrical Properties of Aggregates Part 1: Determination of Particle Size Distribution—Sieving Method. Concrete Society: Farmington Hills, MI, USA.

[18] EN, 1097-6: 2013-Tests for mechanical and physical properties of aggregates. Determination of particle density and water absorption.

[19] EN, 1097-5: 2008 Tests for mechanical and physical properties of aggregates. Determination of the water content by drying in a ventilated oven: British Standards Institution, London, UK.

[20] Biró, A., & Lublóy, V. (2021). Classification of aggregates for fire. Construction and Building Materials, 266, 121024. https://doi.org/10.1016/j.conbuildmat.2020.121024.

[21] Földvári, M. (2011). Handbook of thermogravimetric system of minerals and its use in geological practice (Vol. 213, pp. 1-180). Budapest: Geological Institute of Hungary.

[22] British Standards Document BS EN 12390-3. Testing Hardened Concrete—Part 3: Compressive Strength of Test Specimens. Management Centre, Brussels, 2009.

[23] British Standards Document BS EN 12390-5. Testing hardened concrete—Part 5. Flexural strength of test specimens. https://doi.org/10.3403/30360073U.

[24] Seyam A. M., Nemes R. (2022), Impacts of Aggregate Type and Elevated Temperature on Flexural Tensile Strength of Concrete. 14th fib International PhD Symposium in Civil Engineering. Rome, Italy.

[25] Seyam A. M., Nemes R. (2022), Shear Strength Behavior of Lightweight Aggregate Concrete Subjected to Elevated Temperature. fib International Congress 2022. Oslo, Norway.

[26] Taylor, H. F. (1997). Cement chemistry (Vol. 2, p. 459). London: Thomas Telford.

[27] Petrounias, P., Rogkala, A., Giannakopoulou, P. P., Kalpogiannaki, M., Laskaris, N., & Lampropoulou, P. (2022). The role of the aggregate shape on the compressive strength of concrete using a new micro geo-informatics methodology. Micron, 161, 103333. https://doi.org/10.1016/j.micron.2022.103333

[28] Neville, A. M. (1995). Properties of concrete (Vol. 4, p. 1995). London: Longman.

[29] Jozefaciuk, G., & Czachor, H. (2014). Impact of organic matter, iron oxides, alumina, silica and drying on mechanical and water stability of artificial soil aggregates. Assessment of new method to study water stability. Geoderma, 221, 1-10. https://doi.org/10.1016/j.geoderma.2014.01.020

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