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INFLUENCE OF VARIOUS TYPES OF ROCK AGGREGATES ON SELECTION OF THE WORKING PARTS MATERIAL IN CIVIL ENGINEERING

V. Lazić[1], M. Mutavdžić[2], R. Nikolić[1,3], S. Aleksandrović[1], D. Milosavljević[1], B. Krstić[1], R. Čukić[1]

[1]University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia
[2]Road Building Company Kragujevac, Tanaska Rajića 16, 34000 Kragujevac, Serbia
[3]University of Žilina, Faculty of Civil Engineering, Univerzitna 1, 010 26 Žilina, Slovakia

Abstract: *In this paper are presented results of theoretical and experimental investigations and mutual comparison of various types of rock aggregates from the aspect of working parts wear of different machines for preparation and deposition of the rock materials on roads. Here are considered only the most important types of building stones: limestone, dolomite marble, calcite-dolomite marble and andesite, which are exploited at four sites in Republic of Serbia. Those aggregates are convenient for manufacturing of certain layers of the driveway constructions on roads, streets, airports, as the base layer on railways and for preparation of various types of asphalt and concrete. In selection of rocks for depositing on roads, it is necessary to know both their general and specific properties. It is necessary to conduct the mineralogical-petrographic and physical-mechanical investigations and, if needed, certain special ones, as well.*

The civil engineering machines for manufacturing and building-in materials in various structural objects are exposed to different types of high loads, what is especially true for some of their working parts, which come into direct contact with the rock materials. The working life of those machines is directly dependent on the type of the building material as well as on maintenance. In exploitation, the construction mechanization is subjected to various types of corrosion and wear, and some of its parts are occasionally subjected to impact loads, as well. Certain parts are also frequently in contact with various types of stones, sands, soil, asphalt, concrete and occasionally with water.

Key words: *rock materials, aggregates, minerals, working parts, civil engineering mechanization.*

1. INTRODUCTION

Civil engineering machines for manufacturing and building in materials during construction of various building objects are subjected to different types of loads, especially some of their working elements, which are in direct contact with rock materials. Working life of construction machines' parts is directly dependent on the kind of the rock materials, properties of construction mechanization working parts and exploitation and maintenance conditions. Those machines are, during operation, exposed to different types of wear and corrosion, some working part are even exposed to occasional impact loads. Some parts of construction machines are frequently in contact with various kinds of rocks, sands, soil, asphalt, concrete, sometimes are even exposed to influence of water.

Knowing physical-mechanical properties of the rock minerals are of a special importance, both for their exploitation and for their processing and building in. Since the matter of speaking are the complex tribo-mechanical processes, in which take part different elements of construction mechanization, rocks and third objects, it is especially important to properly select material of the construction machines' working parts, as well as the technology for reparation of the damaged and worn parts of those machines.

Based on investigations of the construction rocks from four available sites, the useful data were obtained both for design and reparation of the working parts of machines for minerals' exploitation, their processing and building into roads.

2. THE MOST IMPORTANT TYPES AND PROPERTIES OF ROCK MATERIALS

Rocks mainly consist of seven groups of minerals: silicates, carbonates, oxides, sulphates, sulphides, chlorides and hydroxides. To get a more complete picture about number of different minerals that rocks are made of, it is necessary to emphasize that only the silicate group contains about 800 minerals, categorized into various subgroups. Mineral masses in the Earth's crust can be found in forms of compounds – as solid rocks or in the unbound – dispersed form. Thus the rocks are being divided, according to strength, into weak, solid and exceptionally solid rocks, since minerals can be in the crystal, crystallite or amorphous form. Rock properties can be significantly changed due to action of water, frost or heat; thus it is highly important to know the laws of those changes. The most important properties of rocks are petrographic, physical, mechanical and technological [1-8]. All the rocks that are contained in the Earth's crust can be classified in three major groups: *magmatic*, *sediment* and *metamorphic* rocks.

In this paper are investigated properties of stones from the four near-by sites: limestone, dolomite marble, calcite-dolomite marble and andesite. The most exploited (over 70 %) is the limestone from the "Vučjak" site, thus this particular stone was taken as representative for rocks' properties experimental investigations.

3. DETERMINATION OF PETROGRAPHIC PROPERTIES

The most important petrographic properties of rocks are: *mineral composition*, *structure* and *texture*. *The structure of rocks* consists of mineral crystallite grains, whose shape and strength depend on way of coalescence during the rock formation. *The texture of rocks* consists of minerals spatial distribution and occupancy. Petrographic properties of rocks were tested according to standard SRPS.B.B8.002:1989.

The limestone site "Vučjak" mainly consists of organogenic-detritic[1] limestone. The rock's texture is massive. i.e., the mineral grains are not regularly distributed within the substrate. In Figure 1 are presented macroscopic and microscopic appearances of this rock [6].

The dolomite marble site "Samar" mainly consists of the dolomite marble. The structure of this type of rock is granoblastic. Texture is massive and noncompact. In Figure 2 are presented macroscopic and microscopic appearances of this rock [6].

The calcite-dolomite marble site "Gradac" mainly consists of this type of rocks. The rock's texture is homogeneous and compact. In Figure 3 are presented macroscopic and microscopic appearances of this rock [6].

The andesite site "Šumnik" mainly consists of this type of rock. The rock's texture is massive. In Figure 4 are presented macroscopic and microscopic appearances of this rock [6].

4. EXPERIMENTAL DETERMINATION OF SOME ROCKS PHYSICAL PROPERTIES

For construction of roads the most frequently experimentally tested are the following rocks' physical properties: specific mass, bulk mass, porosity, water absorption and compactness, since those properties directly influence changes of mechanical and technological properties of rocks and their aggregates.

4.1. Determination of specific mass (density) of rocks

In Table 1 are presented average values of specific mass of various rocks' samples [6].

4.2. Determination of rocks' porosity

Water absorption is defined by ratio of water mass and mass of solid mineral substance; for various types of rocks it ranges from 1.5 to 4.4% [6].

4.3. Determination of rock compaction possibilities

Determination of the rock bulk mass can serve as criterion for estimates of possibility of their compacting in the infilling state, what is of a great importance in construction of building objects. Complete investigation of compaction possibility of rocks requires: determination of granulometric composition, compacting possibility by the Proctor test and the Californian capacity index (cf. [1], [3-4], [7], [9 - SRPS B.B8.030: 1986]).

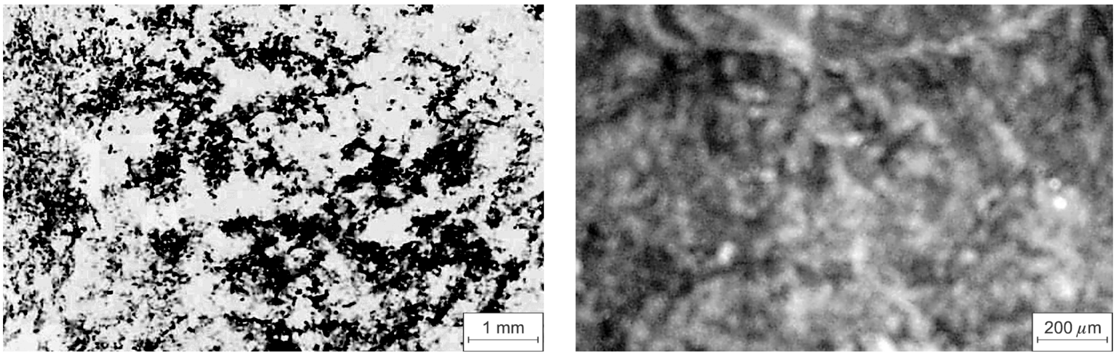
4.4. Influence of water, low and elevated temperatures on rock content changes

Water, low and high temperatures significantly influence some of the rocks' properties. In contact with water at low temperatures (< 0° C) and high temperatures (>100° C), the minor changes in rocks are observed, while at temperatures lower than - 25° C and higher than 500° C, the significant changes occur.

Low temperatures (frost) significantly affect rock properties, especially if the temperatures are variable. Alternating heating and cooling of rocks

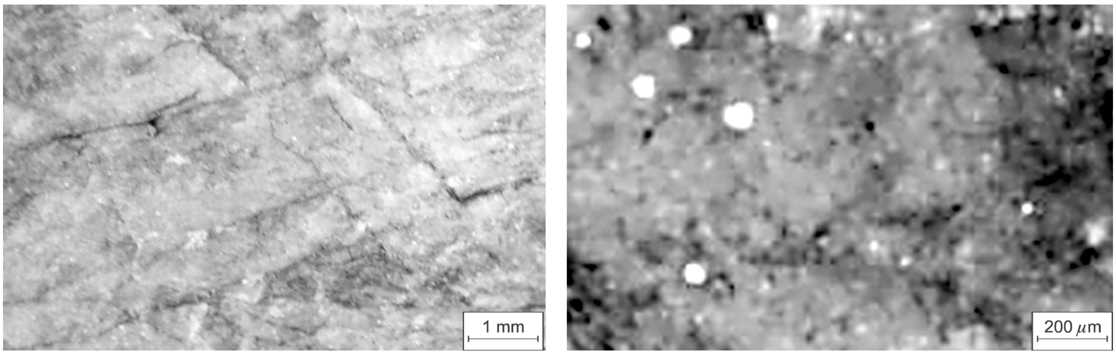
[1] Detritus (latin): aggregate of small particles of crushed rocks

causes big changes of their properties. All the dry rocks endure well the low temperatures actions, while the wet rocks and rocks completely saturated with water have significantly lower resistance, since their destruction occurs due to freezing of water in cavities.



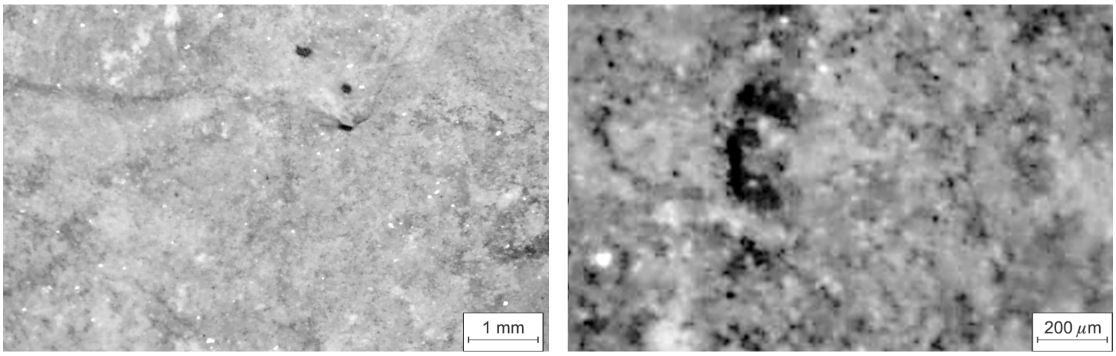
a) b)

Figure 1. Appearance of limestone structure: a) macroscopic appearance, b) microscopic appearance.



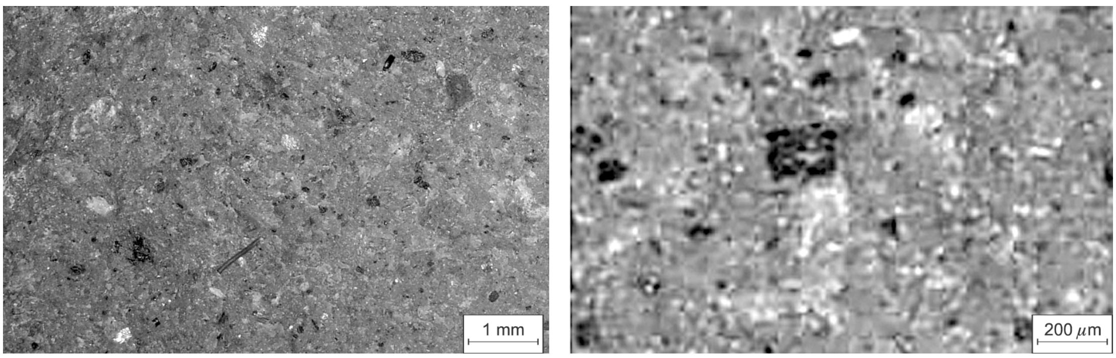
a) b)

Figure 2. Appearance of dolomite marble structure: a) macroscopic appearance, b) microscopic appearance.



a) b)

Figure 3. Appearance of calcite-dolomite marble structure: a) macroscopic appearance, b) microscopic appearance.



a) b)

Figure 4. Appearance of andesite rock structure: a) macroscopic appearance, b) microscopic appearance.

Table 1. Bulk masses of tested rock samples.

Tested rock property	Limestone - Vučjak	Dolomite marble - Samar	Calcite-dolomite marble - Gradac	Andesite - Šumnik
Bulk mass with pores, $\gamma_v = m_s/V$	2690	2780	2820	2630
Specific mass without pores and voids, $\rho_s = m_s/V_s$	2730	2870	2850	2750
Bulk mass coefficient, $i = \gamma_v/\rho_s$	0.985	0.969	0.989	0.956

All types of rocks well endure action of elevated temperatures up to 500° C. Further temperature increase leads to visible changes: loss of characteristic ringing sound at impact, significant decrease of strength and appearance of crumbling or total destruction if poured over with cold water. At high temperatures (over 850° C) more durable are rocks made of minerals whose heat conductivity is significantly different. More durable are firm and fine-grained rocks than the porous and coarse ones. At that temperature granites crack irregularly, while the sand rocks usually crack parallel to stratification. Limestones and marbles possess good strength up to the calcification temperature (~ 800° C), when they transform into quicklime (CaO). At high temperatures quartzites, quartz sandstones with silicon binder, clays, serpentinite, serpentinite and chromite are stable. Fireproof bricks are made of magnesite and chromite.

5. EXPERIMENTAL DETERMINATION OF MECHANICAL ROCK PROPERTIES

Of all the mechanical properties, the most frequently investigated are compressive strength, hardness, elasticity, toughness and wear resistance. The rocks' mechanical properties tests are defined by corresponding standards [9- SRPS B.B8.-012:1987 do SRPS B.B8.018:1957].

5.1. Determination of rocks hardness

The basic mineral that all the limestones are made of is calcite, thus their hardness is usually about 650 HB. Hardness of calcite-dolomite mineral depends on percentage shares of calcite and dolomite; it is usually within limits 650-850 HB, while the dolomite marble hardness is usually about 850-1150 HB. Hardness of various types of andesites is within the wide range and it depends on their type. The biotitic andesite has hardness similar to limestone, 550-700 HB, ensitite andesite 750 HB, amphibolic andesite 1000-1500 HB, while content of quartz SiO_2 (55-65%) in andesite can increase hardness up to 1800 HB. Hardness of rocks has strong influence on their processing and application, but also on damage of the working parts of the construction machinery during processing and building-in of the rock materials. This is why one must use metals that possess high hardness, with carbides in the metal substrate, or relatively soft steels, which can, under pressure or impact load, provide martensitic transformation of austenite – like the Hadfield steels [10].

5.2. Determination of rocks impact toughness

In Table 2 are presented values of impact hardness of rock materials from the four studied sites. Testing was conducted in three mutually perpendicular directions (I-I is parallel to rocks' stratification direction; II-II is perpendicular to I-I and lies in stratification plane and III-III is perpendicular to direction of the rock's stratification). This is important to emphasize, since rocks are highly anisotropic due to stratification and schistosity-inhomogeneity of rocks.

Based on these results one can conclude that those rocks have relatively low impact toughness; according to the fracture site appearance the similar conclusion can be drawn as well, since the fracture surface is rough and with sharp edges.

5.3. Determination of rocks elasticity

This property is related to solid bound rocks and it depends on type and hardness of rock minerals, structure and texture and minerals freshness, moisture, strength and direction applying of load, etc. Fine-grained rocks have higher values of elasticity modulus, than the coarse rocks of the same composition.

For the stratified and inhomogeneous rocks the elasticity modulus is higher in the direction perpendicular to than parallel to stratification and schistosity. By testing the limestone samples the following values were obtained: average Poisson's ratio ν = 0.36, elasticity modulus E = 50247 MPa, shear modulus G = 18608 MPa and bulk modulus K = 59714 MPa.

Table 2. Impact toughness of some types of rocks.

Impact toughness, *MPa*	Limestone - Vučjak	Dolomite marble - Samar	Calcite-dolomite marble - Gradac	Andesite - Šumnik
Direction I-I	22.40	17.00	27.20	13.40
Direction II-II	24.20	20.60	26.10	17.20
Direction III-III	28.80	24.60	28.30	22.40
Average value	25.13	20.73	27.20	17.67

5.4. Determination of rocks' strength

Experimental determination of rocks' strength is usually done with at least three samples, most frequently with 5 samples, cut out from the rock in three mutually perpendicular directions; samples are of prismatic form; the whole is defined by adequate standards [9- srps b.b8.012:1987 to srps b.b8.018:195].

Compression strength. Determination of the compression strength was done on dry and water saturated cubic samples, cube edge is 40 ± 1 *mm*, with ground and plan parallel surfaces. The average value of the compression strength for the limestone from site Vučjak (15 samples, 5 for each direction) was R_{cm} = 131 *MPa*. Tests of samples from other sites were done in the same way. For obtaining the compression strength after 25 cycles of freezing 3 cubic samples were used; cube edge was 1000 ± 1 *mm* (Table 3).

Tensile strength. Determination of the tensile strength is conducted less frequently though it is also an important property. The tests were done on samples of the same shape and dimensions as for the compression strength; but only dry samples were tested. The average value of the tensile strength of the tested limestone samples was R_m = 6.00 *MPa*, while in large number of references reported value is about 1.5 *MPa* for the porous limestones and 6.4 *MPa* for the firm limestones. Tests of samples from other types of rocks were done in the same way and results are shown in table 4.

Bending strength. Bending tests were done on one dry sample per each type of rocks, for the direction which is perpendicular to stratification and schistosity propagation, in order to obtain the best possible results, [6].

Shear strength. Determination of shear strength was done only on limestone from the Vučjak site by the direct shear method, by the Casagrande testing device, [6].

5.5. Determination of rocks' wear resistance

Experimental investigation of the rocks' wear resistance is defined by corresponding methods: the Bome method, the Los Angeles and the Deval procedure, [9]. By the Bome method the wear resistance is checked on the cubic samples, while the other two methods are more frequently applied for the rock aggregates; results are presented in [6].

Table 3. Compression strength of some rock materials.

Rocks' type and origin	Compression strength, R_{cm}, *MPa*			Softening coefficient, K_{soft}
	Dry samples	Water saturated samples	Samples after 25 freezing cycles	
Limestone - Vučjak	131	123	117	0.94
Dolomite marble - Samar	150	136	130	0.91
Calcite dolomite marble - Gradac	161	140	138	0.87
Andesite - Šumnik	195	186	184	0.95

Table 4. Tensile strength of some rock materials.

Rocks' type and origin	Tensile strength, R_m, *MPa*			Average values
	Direction I-I	Direction II-II	Direction III-III	
Limestone - Vučjak	5.97	6.14	5.89	6.00
Dolomite marble - Samar	5.26	5.42	3.72	4.80
Calcite dolomite marble - Gradac	5.64	5.36	4.03	5.00
Andesite - Šumnik	9.48	9.82	8.90	9.40

6. SELECTION OF MATERIALS FOR THE CONSTRUCTION MECHANIZATION WORKING PARTS

Large number of parts of the construction mechanization (hoop's teeth, rippers, mixers' blades, knives for lifting and removing asphalt, knives-blades for channels digging, crushers impact beams etc.) are, during operation, in indirect or direct contact with rock materials, and, depending on the role and function of the part, they are exposed to various types of wear [10-12]. Mainly one deals with abrasive wear or a combination of several types of wear.

The main factors in selection of materials exposed to wear are their chemical composition and structure. Those materials are mainly steels and (white) cast irons. The most resistant to wear are materials of high hardness. Though that characteristic can not be the only criterion, it is mainly used for quality estimates of materials exposed to wear.

Depending on the degree of wear, machines' working parts could be replaced by the new ones, or could be subjected to reparatory hard-facing. When selecting the reparation technology, mechanism of abrasive wear is being analyzed, both theoretically and experimentally, taking into account hardness and microstructure of parts, and related wear resistance in laboratory and real operating conditions. That represents the basis for selection of the optimal procedure, technology and filler metal for working surfaces regeneration.

Investigations, until now conducted by these authors, have shown that the working life of the properly regenerated parts exceeds several times the new parts working life. Besides that, the machine down-time, assortment and quantity of the necessary spare parts are reduced. All these point to complexity of materials selection for the working parts of construction mechanization, as well as to importance of knowing the properties of the rock materials.

7. CONCLUSION

In this paper are presented investigation results of the rock materials physical and mechanical properties tests, for four types of rock materials most frequently applied in construction of driveways. The conclusion was reached that those materials are firm and homogeneous rocks, of medium to high hardness. It was determined that the compression strength values are on average 10-40 times higher than the shear, bending and tensile strengths, while the wear resistance is good in majority of studied rocks, being especially high for andesite.

Obtained results enable estimates of the individual rock material's quality and point to the complexity of the material selection for the working parts pf construction mechanization. Experimental results of rock materials properties and the complex working conditions of the tribo-system, can serve and must be taken into account in selection of the base metal and reparation technology of the damaged parts of the construction mechanization.

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