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SUITABILITY ASSESSMENT OF GRETAGEOUS LIMESTONES FROM THERMO (AITOLOKARNANIA, WESTERN GREECE) FOR THEIR USE AS BASE AND SUB-BASE AGGREGATES IN ROAD-CONSTRUCTION

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Abstract

This paper focuses on the assessment of mineralogical, petrographical and physico-mechanical properties of limestone formations in order to evaluate their suitability as road construction aggregates. Research focuses on Olonos-Pindos zone limestones of Createaceous age in Aitoloakarnania province, Western Greece. Special emphasis was given on comparing the mechanical properties to the mineral components. The results were evaluated in accordance with Greek and International suitability Standards for road construction aggregates. It was finally concluded that the physical and mechanical properties of the tested rocks are in compliance with the suitability Standards and that they can be used as road-construction aggregates.

***Keywords**: Aggregates, limestone, physico-mechanical properties, Thermo Aitoloakarnania.*

1. Introduction

The increasing demand for crushed rock aggregates in various applications and especially the requirement for hard aggregates in numerous engineering projects of Greece, have increased the necessity for the detection of carbonate rocks which are suitable for the production of aggregates used for: bases and sub-bases, improvement layers, bituminous mixtures, concrete and embankments. Additionally, carbonate rocks are used in various environmental applications such as for erosion protection, for the stability of natural or artificial slopes and for filters (Spyropoulos, 2005).

This paper investigates potential aggregate resources from the Cretaceous limestone formations of the Olonos-Pindos zone. Six representative samples were examined (AT9A, AT9B, AT13A, AT13B, AT22), in order to determine their suitability as road bases and sub-bases. The quality of the collected limestones was assessed based on their physico-mechanical properties, as well as on their mineralogical and textural features.

2. Geological setting

The studied carbonate rocks of Thermo (Aitoloakarnania province, Western Greece) (Fig. 1), cover a total area of 37 km^2. They comprise part of the lower unit (thickness more than 1000 m) of the Olonos-Pindos zone, which includes pelagic limestones of Triassic to Upper Cretaceous age. These limestones are intercalated with radiolarites of Middle Jurassic to Lower Cretaceous. The Upper

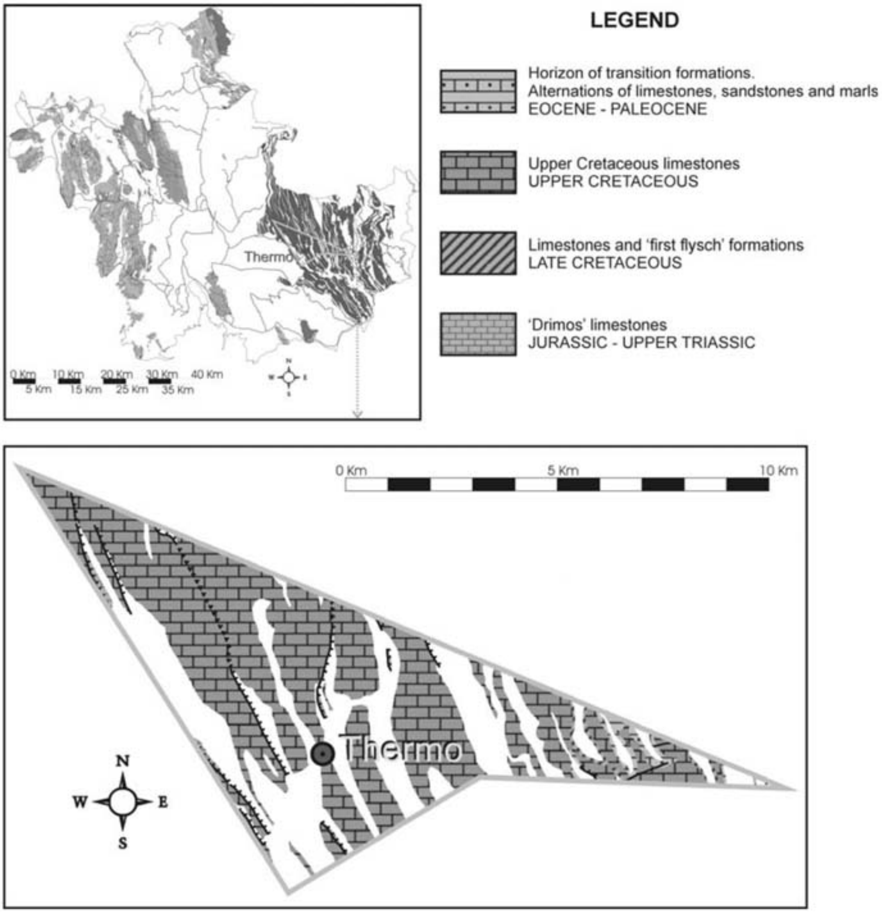

Fig. 1: Geological map of Thermo (Aitoloakarnania province). The general map is an extract from the "Thermo" map sheet, I.G.M.E. (1977).

Cretaceous limestones, which comprise the upper part of this lower unit, are biomicritic and medium-bedded with intercalations and nodules of flint. The colour of these limestones varies from gray to whitish and becomes reddish at the lower parts, while their thickness varies from 200 to 400 m (Katsikatsos, 1992; Mountrakis, 1985).

The Cretaceous carbonate rocks (Fig. 1) cover the greatest area (34 km^2) among the formations of the Olonos-Pindos zone and occur in beds up to 20 cm thick. The rock slopes of the studied area are cut by joints with opening up to 3-4 cm and are characterized by manifold disruption and intense folding. All these features have led to local destruction of the original structure of these rocks (Fig. 1). Statistical analysis of the strike of the limestone beds revealed that the main direction strikes NNW – SSE and dips 15^o to 60^o to the ENE or WSW.

3. Petrography

The studied Upper Cretaceous carbonate rocks were collected from representative localities of quarry faces or natural slopes, with a view to be fresh and to represent the full variability of the quarry

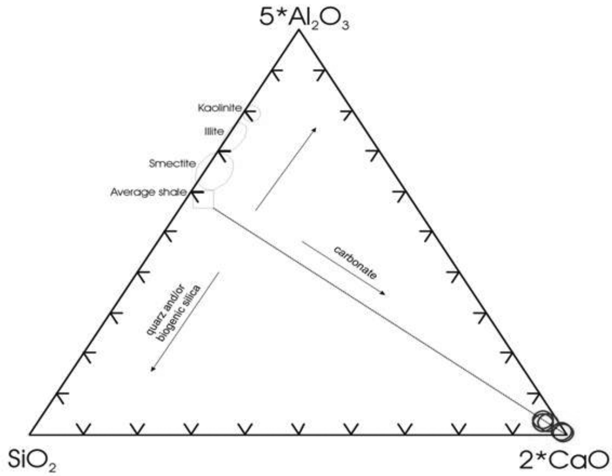

Fig. 2: Plot of the analysed samples on the Al_2O_3-SiO_2-CaO diagram for sedimentary rocks.

products. Most of these rocks are macroscopically whitish to gray with a dense network of sparitic veins, except for samples AT9B and AT22B, which have a yellowish pink colour. The microscopic examination was carried out using polarized microscopy at the Laboratory of Research Mineral and Rocks, Department of Geology, University of Patras, as well as at the Laboratory of Electron Microscopy and Microanalysis, University of Patras. Petrographic examination indicated that samples AT9A, AT9B, AT13A and AT22B are micritic limestones and according to Folk (1959, 1962) are classified as packed biomicrites (AT9A) and sparse biomicrites (AT9B, AT13A and AT22B), whereas according to Dunham (1962) are classified as wackestone (AT13A and AT22B), bioclast packstone (AT9A) and bioclast mudstone (AT9B). Samples AT13B and AT22A are sparitic limestones and are classified as sorted biosparites (AT22A) and as sorted endobiosparites (AT13B) according to Folk, and as biograinstone (AT22A) and endobioclast grainstone (AT13B) according to Dunham (1962).

4. Whole-rock geochemistry

Whole-rock analyses in six representative Cretaceous carbonate samples are listed in Table 1. TiO_2, Fe_2O_3, MgO, K_2O and P_2O_5 abundances are lower than the Greek and Global average values. Low P_2O_5 is a result of the absence of apatite, which frequently exists in carbonate rocks, while the low TiO_2 values are related to the absence of detrital heavy minerals. SiO_2 in three samples (AT9B, AT13A, AT22B) is higher than the Greek average value (1.80%) whereas samples AT9A, AT13B και AT22A show lower values. Samples AT9B, AT13A and AT22B are richer in Al_2O_3 relative to the Greek average value, most likely reflecting the occurrence of clay minerals. Samples AT9A, AT9B, AT13B και AT22B are richer in Na_2O relative to the Greek and Global average value probably due to the presence of anhydrite and feldspars. All samples are rather rich in MnO with the highest value in sample AT9A (0.07%). Samples with higher SiO_2 values show also lower loss-on-ignition values, reflecting the lower calcite abundances.

On an Al_2O_3-SiO_2-CaO diagram (Fig. 2), the analysed samples plot close to the CaO apex, suggesting that they are poor in clay- and silicate-fraction.

5. Physiomechanical properties

Several laboratory tests were performed for the suitability assessment of the Cretaceous limestones from Aitoloakarnania as aggregates (Table 2). These tests were carried out according to the American (ASTM) and Greek (ELOT) Standards. Selection of samples was based on their mineralogical composition that strongly controls the quality of aggregate materials (Zarif & Tuğrul, 2003; Tsikouras et al., 2005; Pomonis et al., 2007). Physicomechanical properties were estimated in six representative samples, which include micritic (AT9A, AT9B, AT13A and AT22B) and sparitic limestones (AT13B και AT22A).

5.1 Physical properties

Apparent density, bulk density (ASTM C-127), water-absorption (ASTM C-128) and sand equivalent (ASTM D-2419) were carried out. Normal density aggregates show values ranging between 2-3 gr/cm^3, which are broadly used in several construction works. Light-weighted aggregates have densities <2gr/cm^3 whereas heavy aggregates are those with density >3gr/cm^3. Apparent density in the analysed samples ranges from 2.68 gr/cm^3 to 2.71 gr/cm^3 and are classified as normal aggregates.

Water-absorption was estimated after 24 hours immersion of the samples in water and ranges between 0.40% and 1.30%; samples AT9B AT22 have the maximum and minimum values, respectively.

Aggregates with sand equivalent values >50% are considered suitable for base and sub-base aggregates in road constructions. The sand equivalent (AASHTO T176-65) ranges in the analysed samples between 63 % and 78%, suggesting their good quality.

5.2 Mechanical properties

The estimated mechanical properties according to Greek and international standards include the riprap soundness using Na_2SO_4 (ELOT EN 1097-01), the toughness and abrasion resistance using the Los Angeles abrasion test (L.A.A.V.; ASTM C 535), the uniaxial compression strength (ELOT 408), and the maximum Proctor density (E105-86). The results are listed in Table 2. The Los Angeles values range between 23.26% and 27.52%, the riprap soundness (Na_2SO_4) yielded values between 2.70% and 3.70%, the uniaxial compression strength ranges between 49.30MPa and 68.00MPa, and the maximum Proctor density is in the range of 2176-2207 kgr/m^3.

Using linear regression analysis (Bevington & Robinson, 2002) it is clearly shown that there is an antipathetic relation between the Los Angeles values and the uniaxial compressive strength values with a correlation coefficient R^2=0,8065 (Fig. 3). Los Angeles values also plotted against the whole-rock major oxides. SiO_2 abundance shows positive correlation with the Los Angeles values, indicating that with increasing silica there is a decrease in the rock quality (Fig. 4); similar behaviour is also suggested with increasing Al_2O_3 contents. The Los Angeles values show also significant positive correlation with the riprap soundness values (Fig. 5), revealing that the more durable in toughness and abrasion a rock is the more durable in weathering under variable climatic conditions. Finally, a moderate correlation between the Los Angeles values and the maximum Proctor density values is observed in the analysed (Fig. 6).

6. Discussion

Mineralogical and textural characteristics, as well as the degree deformation and porosity are some critical factors in the quality of aggregates (Hartley, 1974; Kazi & Al-Mansour, 1980; Al-Jassar &

Table 1. Whole-rock geochemical analyses of representative samples from Cretaceous limestones from Thermo (-: below detection limit)

Major elements (wt %)	AT9A	AT9B	AT13A	AT13B	AT22A	AT22B	Global Average Value[1]	Greek Average Value[2]
SiO_2	0.81	3.22	3.33	0.52	0.72	2.29	5.20	1.80
TiO_2	-	0.02	0.01	-	-	0.01	0.07	-
Al_2O_3	0.14	0.78	0.62	0.08	0.15	0.59	0.80	0.50
$Fe_2O_3^t$	0.08	0.40	0.32	0.10	0.10	0.31	0.50	0.50
MnO	0.07	0.04	0.05	0.05	0.05	0.05	0.05	0.02
MgO	0.40	0.37	0.36	0.31	0.56	0.39	7.90	2.80
CaO	53.96	53.32	53.84	57.34	53.56	53.71	42.60	51.60
Na_2O	0.07	0.07	0.05	0.08	0.1	0.07	0.05	0.05
K_2O	-	0.19	-	-	0.03	0.08	0.30	0.05
P_2O_5	0.02	0.03	0.03	0.03	0.03	0.03	0.09	-
LOI	43.30	41.77	41.92	40.32	43.57	42.50		
Total	98.83	100.21	100.53	98.81	98.91	100.00		

[1] Mason & Moore (1982), [2] I.G.M.E. (1997)

Table 2. Results of the physicomechanical properties of the analysed samples from Thermo

Sample No.	AT9A	AT9B	AT13A	AT13B	AT22A	AT22B
Bulk density (gr/cm^3)	2.69	2.69	2.71	2.70	2.70	2.68
Apparent density (gr/cm^3)	2.65	2.63	2.66	2.66	2.64	2.66
Water absorption (%)	0.80	1.30	1.10	0.9	1.20	0.40
Los Angeles (%)	23.26	25.79	27.50	24.55	27.11	27.52
Riprap soundness (%)	2.70	3.40	3.70	3.20	3.70	3.50
Uniaxial compressive strength (MPa)	68.00	58.85	49.30	55.00	50.00	51.00
Sand equivalent (%)	68	63	69	70	73	72
Maximum Proctor density (kgr/m3)	2176	2192	2201	2176	2207	2189

Hawkins, 1991; Smith & Collis, 2001; Jensen et al., 2010).

Apparent and bulk density of the Createceous limestones from Thermo show moderate to slightly high values and are within the acceptable limits of aggregates suitability (NBG 1985, Shakoor et al. 1982, Cargill, 1989). Water absorption is another important factor related to durability of the materials. Experimental results have shown that rocks with water absorption values higher than 3% are vulnerable to shock changes of temperature (Shakoor et al., 1982). Samples AT9B (1.3%), AT13A (1.10%) and AT22A (1.20%) show the highest water absorption values compared to the rest samples, most likely due to their higher porosity and participation of clay minerals that strongly absorb

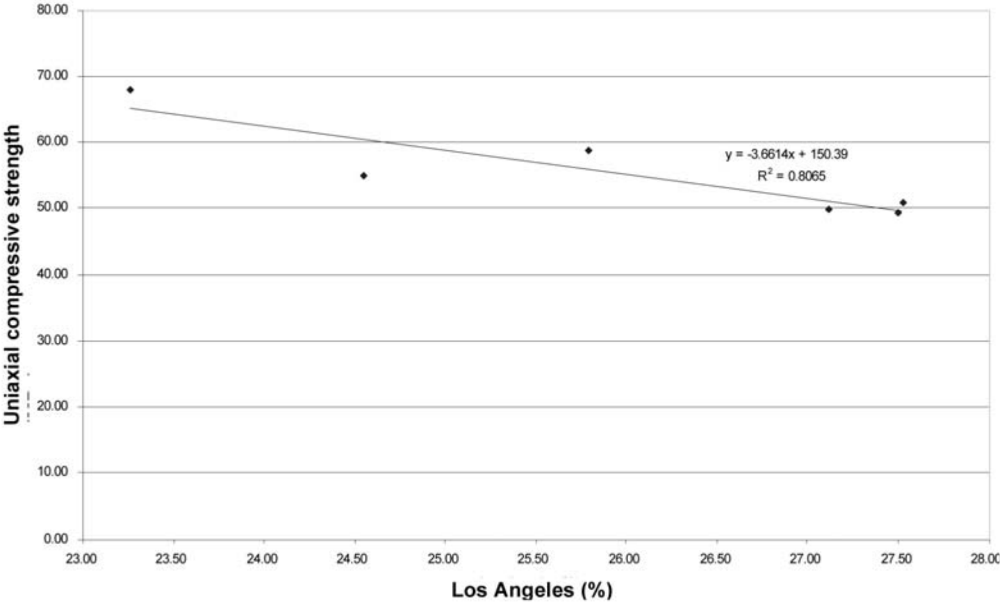

Fig. 3: Plot of Los Angeles values vs. uniaxial compressive strength values of the analysed samples from Thermo.

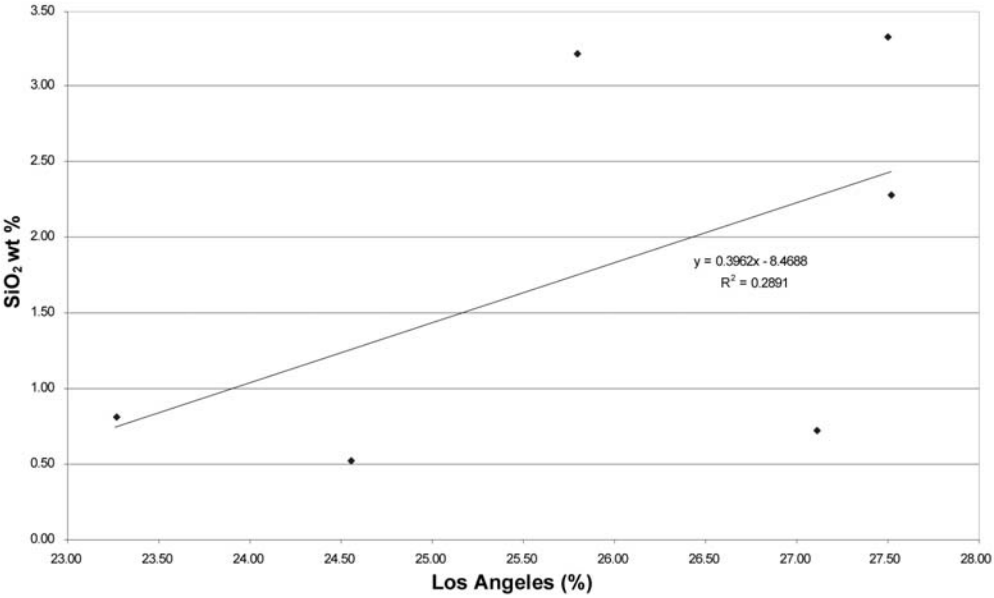

Fig. 4: Plot of Los Angeles values vs. SiO_2 contents of the analysed samples from Thermo.

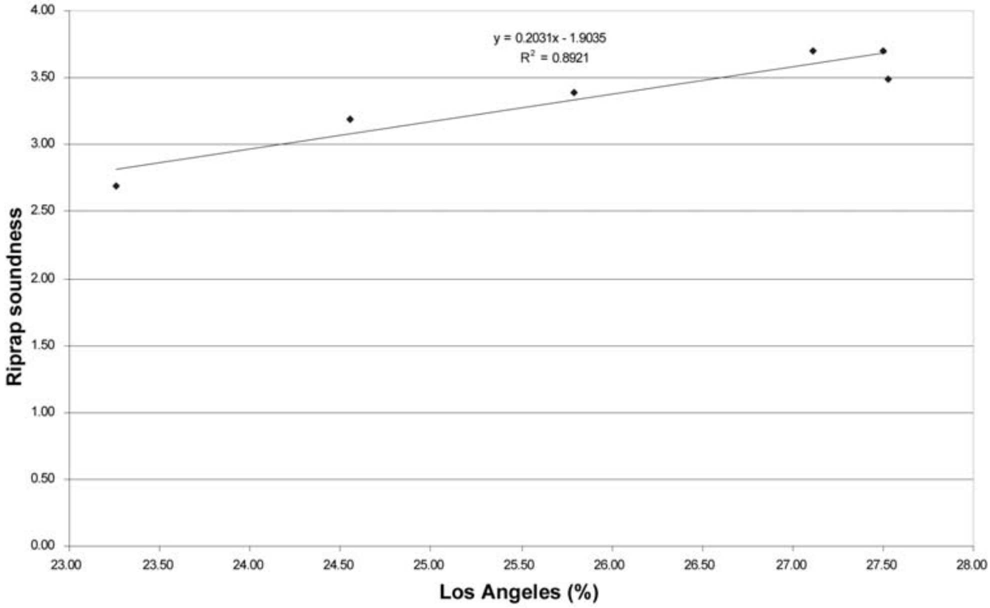

Fig. 5: Plot of Los Angeles values vs. riprap soundness using Na_2SO_4 of the analysed samples from Thermo.

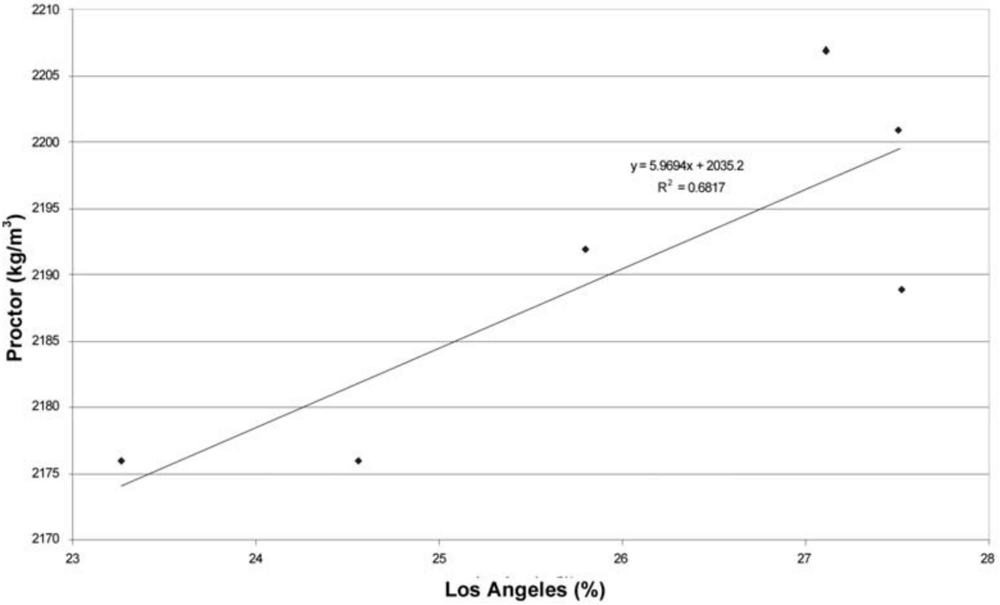

Fig. 6: Plot of Los Angeles values vs. maximum Proctor density of the analysed samples from Thermo.

water. A test that simulates the volume changes of aggregate materials and estimates their durability under climatic variations is the soundness of riprap (Smith & Collis, 2001). For this purpose, it is used Na_2SO_4 or $MgSO_4$, which crystallize in the pores and joints of the aggregates and disintegrate them after repeated freeze-thaw and dry-wet cycles (Bloem, 1966). In this study, we used a Na_2SO_4 solution and the obtained riprap soundness values of the Cretaceous limestones are below the limit of 12, for their use as bases and sub-bases in road construction

The Los Angeles values are low whereas the sand equivalent values are high in the analysed Cretaceous limestones from Thermo. According to the standards of the Greek Ministry of Environment the upper limit of Los Angeles and the lower limit of sand equivalent, for the suitability of aggregates for road construction works, are 30 and 50, respectively. Our samples clearly fulfill these prerequisites and hence it is strongly suggested that they are suitable for use as bases and sub-bases aggregates. The somewhat higher Los Angeles values of samples AT22A and AT22B are interpretaed as the result of their sparitic texture (e.g. Zarif & Tuğrul, 2003; Sabatakakis et al., 2008).

7. Conclusions

Petrographic investigation in Cretaceous limestones from Thermo showed that they comprise rocks with both micritic and sparitic textures; they are intensely tectionised and frequently they are cut by joints filled with recrystallised calcite. Geochemical analyses reveal that they contain insignificant impurities and are similar to the Greek and Global average limestones. Physicomechanical properties such as Los Angeles, soundness of riprap, uniaxial compressive strength and maximum Proctor density are correlated each other. Moreover, there is a positive correlation of the Los Angeles values with the SiO_2 abundance in the rocks. Therefore, knowledge of some of these parameters can easily predict the quality of the aggregates.

The studied rocks show values of their physicomechanical properties within the acceptable Greek and international limits and hence they are suitable for their use as bases and sub-bases aggregates in road construction works.

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