Clay-rich Rocks and Mining Wastes for the Production of Lightweight Aggregates with Thermal Insulation Properties

M.G. Stamatakis, H. Bedelean, M. Gorea, D. Alfieris, E. Tziritis, S. Kavouri

The paper focuses on the usage of bentonitic rock waste materials and clayey diatomites (occurred as lignite overburden) as raw materials for the production of lightweight aggregates (LWA) with well-defined properties. The LWA were tested on laboratory scale to identify their efficiency in order to be used in the construction industry. Reconnaissance and detailed field work was carried out in northern Greece. Bulk and reconnaissance samples were collected from the main outcrops for characterisation and laboratory tests. LWA have been obtained without burnable additives by firing from 650 °C to 950 °C, as well as ones mixed with sawdust as burnable constituent (1, 3, 5, 7 and 9 mass-%), and thermally treated at 900 °C and 1100 °C. All of them have been characterized concerning compactness, resistivity, thermal conductivity. Subsequently, lightweight concrete was successfully produced on laboratory scale by using pellets that were considered to be most suitable for this type of application.

1 Introduction

Thermal insulation is defined as the capacity of a material to influence, i.e. reduce the heat flow. Currently, in the construction industry there are several natural and/or artificial materials used as insulation units. Some of them are of organic origin such as various synthetic polymers, vegetable fibers and other organic particles. The most popular currently used non-organic insulation materials are lightweight aggregates (LWA), which are defined as materials lighter than water and more porous than sand, gravel and ground rocks – the latter constituting the so-called "dense" aggregates [1]. According to the European Union Standard UNE-EN-130551-1 (Directive 89/106/CEE), the bulk density of LWA used for concrete, mortar and injection systems has to be less 1200 kg/m^3 (1,20 g/cm^3), while the particle density cannot exceed 2000 kg/m^3 (2 g/cm^3).

M.G. Stamatakis, S. Kavouri, E. Tziritis
National & Kapodistrian University
Department of Geology & Geoenvironment
15784 Athens, Greece

H. Bedelean, M. Gorea
Babeş Bolyai University
Department of Geology
400084 Cluj Napoca, Romania

D. Alfieris
S&B Industrial Minerals SA
14564 Kifissia, Athens, Greece

Corresponding author: H. Bedelean
E-mail: hbedelean@yahoo.com

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LWA can be produced by sintering natural – such as pumice, volcanic ash, expanded perlite and vermiculite, zeolitic rocks, quartz sand – or artificial/processed raw materials: mining residues, glass, fly ash, heavy metal sludge, sewage sludge, dredged silt, polystyrene, rock-wool, SiC-bearing industrial wastes etc. [1–4]. In addition to the above-mentioned natural raw materials used for manufacturing LWA, in several countries worldwide another raw material was tested, i.e. clayey rocks that expand following calcination. As a rule, the original clayey raw material is a bentonitic mudstone or a diatomaceous claystone that mainly contain clay minerals of the smectite group.

The usage of expanded clay, slate, shale and clayey diatomite for the production of lightweight insulation units is developed rapidly in many EU countries, especially in Scandinavia, UK and Germany, and most recently on the Iberian Peninnsula. In most of these countries, the production of artificial LWA is mainly based on burning of clayey rocks that contain expanded clays, such as smectite and vermiculite, commonly using crude oil or sawdust as burnable material [5].

An essential characteristic of all smectite minerals is their ability to absorb tremendous amounts of water and other liquids into their sheet-like crystal structures. This gives bentonite extraordinary swelling and adhesive properties that are exploited commercially by several industries. To be used to produce lightweight aggregates, the clayey raw materials, must meet – among others – conditions of chemical, grain size and mineralogical composition [6].

The diatomaceous (clayey diatomite) rocks from different countries were studied and their effect on the cement properties was determined. The products obtained were characterized and compared with Danish and German commercial products [7–11].

The present paper is focusing on the use of bentonite-rich clays, but also of lignite mining wastes composed of clayey diatomite rocks as natural raw materials for the production of lightweight aggregates (LWA) with well-defined properties, to be mainly used for heat insulation applications. These rocks naturally occur in western Macedonia (lignite overburden) or Thessaly (thick clayey diatomite deposits, Greece). Diatomitic rocks from Greece (Samos Island and Sarantaporo-Elassona) have been previously tested

Fig. 1 **Elassona basin, brick making clays, Drymos site**

Fig. 2 **Florina-Kleidi clayey diatomite as overburden of lignite deposit**

as alternative pozzolanic materials for obtaining composite cements [12]. The usage of mining waste as secondary resources for producing LWA is an example of green construction works.

The LWA may be used as such – for example in road constructions (surfacing materials), geotechnical applications, gardening and hydroponics etc. [13] – or as aggregate materials for classical building materials, in their lightweight counterparts: precast masonry blocks, plasters, loose insulating infills and slabs, mortars, cement, concrete (from no-fines concrete of low density mainly for block production, with densities from 300 – 1200 kg/m^3 to structural concrete ranging from 1000 – 2000 kg/m^3) [14–16]. In all these construction applications, LWA contribute with several advantages to the building materials in which they are incorp-orated: weight reduction, thermal and sound insulation, fire resistance, workability etc.

2 Materials and methods

Reconnaissance and detailed field work was carried out in Greece in some active lignite quarries and other occurrences that contain big amounts of diatomite rock. Bulk and reconnaissance samples were collected from Drymos old quarry (Elassona basin, Thessaly) and Kleidi area, western Macedonia prefectures, for characterisation and laboratory tests and the production of lightweight aggregates (LWA). The study of the raw materials concerned their physical and chemical characteristics (thermal behaviour, mineral and chemical analyses). X-ray diffraction analyses on random powders were performed using a Siemens D5000 unit (40 kV, 40 mA, 1 j/min, CuK$_\alpha$ radiation). The diffractograms were recorded from 5° to 65° 2 θ.

FTIR spectrum of the bentonite sample was recorded using a Jasco 615 spectrophotometer (400 – 4000 cm^{-1}, resolution 2 cm^{-1}). Chemical analyses were performed usig XRF techniques, Philips PW1010 (50 kV, 50 mA). Thermal analyses were perfomed using a SDT Q 600 apparatus. SEM analysis was performed in the Geology Department of NKUA laboratories (Jeol-JSM 5600, EDX, Oxford Link Isis 300). The raw material has been shaped into pellets of 2 – 3 cm in diameter. The pellets were dried at 105 °C, and then fired at various temperatures. Additionally, other pellets were formed by mixing the clayey rock with 1, 3, 5, 7 and 9 mass-% sawdust and fired in a laboratory kiln. The product had rounded shapes (pellets) ranging from 0,5 – 2 cm in diameter. Sawdust was added for increasing the porosity of the final product.

The ceramic aggregates obtained from these raw materials have been characterized by their water absorption capacity (by boiling), apparent density, apparent porosity (by Archimedes' method), mechanical strength (using a Tonitechnic press) and the thermal conductivity (using a HFM 436 Lambda-type equipment).

The lightweight pellets (LWA) produced are used in mixtures with cement (cement : aggregate ratio of 1 : 3 and 1 : 2 respectively) in order to produce lightweight and insulation concrete (LWC). Tests have been carried out on prisms of LWC.

2.1 Raw material characterisation

2.1.1 Geological setting

The Drymos sample is included in the Sarantaporo-Elassona diatomite deposit that may be characterized as the most clay-vermiculite-rich among all diatomites occurring in Greece, as it contains appreciable amounts of smectitic clays and vermiculite, whereas the presence of calcite or other carbonate mineral is negligible. The clayey diatomite beds also contain quartz and feldspar. Silica polymorphs are either opal-A, or detrital quartz. Diagenetic opal-CT is not present in Sarantaporo-Elassona diatomite, indicating a good preservation of the diatom frustules. The diatomite is of lacustrine origin and contains many fossil leaves of Upper Miocene age. One bulk sample was collected from Drymos old quarries, weighing up to 100 kg (Fig. 1).

In western Macedonia (Florina and Kozani basins) there exist some lacustrine basins that host lignite deposits of Upper Miocene and Pliocene age.

Diatomaceous clays have been reported at the SW margin of the Vegora Lake, having Upper Miocene age. After our detailed reconnaissance fieldwork our joint research team discovered a thick clayey diatomite deposit in Kleidi lignite basin, where the diatomaceous rocks occur as thick overburden of xylite-type of lignite, whereas the overburden of Vevi lignite is mostly sandstone with minor marlstone.

All the above mentioned deposits are of Upper Miocene in age. One bulk sample up to 100 kg was collected from Kleidi area.

Another bulk sample of some 100 kg representing clayey diatomite overburden was collected by the Greek team from the Prosilio lignite (Upper Miocene) deposit that is located south of Kozani and near to the Aliakmon River (Fig. 2).

Diatomite layers are usually interbedded with clays, sands and silts, forming a soft, easy to mine overburden of the lignite beds that are exploited. The colour of diatomite is gray to white grey as a result of the mixing with clays. The amount of carbonate minerals is limited, which indicates an almost homogenous composition.

For the purposes of the present research, two samples were selected for further tests, the ones of Drymos and Kleidi.

2.1.2 XRD analyses

In samples from Drymos site, the X-ray diffraction diagarams indicate the presence of quartz, feldspar (albite/anorthite), muscovite, clinochlore and dolomite (Fig. 3). The amorphous phase [opal-A] was determined by SEM.

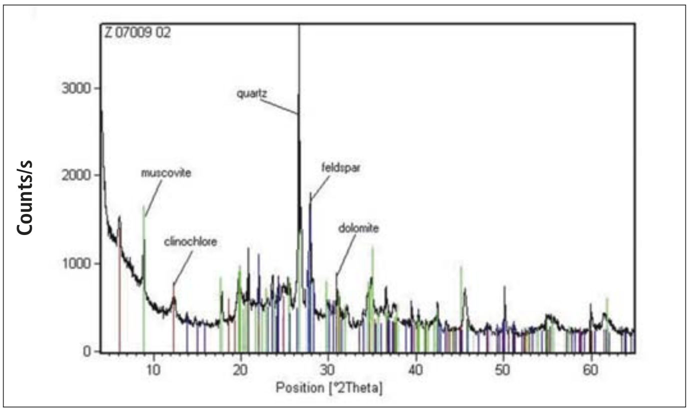

Fig. 3 XRD pattern of clayey diatomite from Drymos

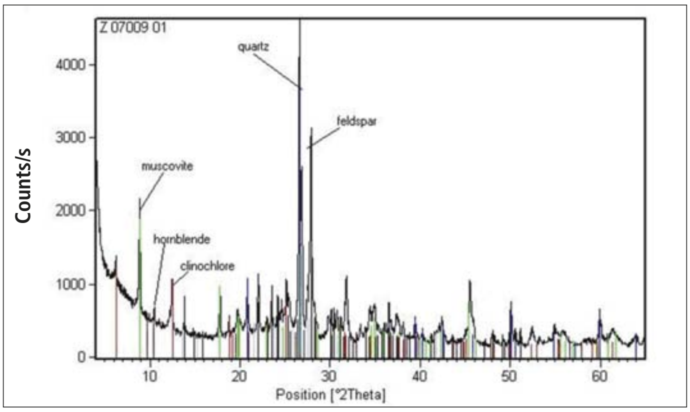

Fig. 4 XRD pattern of clayey diatomite from Kleidi

The X-ray diffraction diagrams performed on random powder of the whole material from Kleidi indicated the presence of quartz, feldspar (albite/anorthite), muscovite, clinochlore, hornblende (Fig. 4). The amorphous phase [opal-A] was determined by SEM.

2.1.3 Chemical composition

The chemical composition of the analyzed two bulk samples is presented in Tab. 1.

The Drymos sample has a higher content of SiO_2 compared with the Kleidi sample. However, the iron content in Kleidi is higher, whereas the alumina content is lower in the Drymos bulk sample. Their trace element content is low, so there is not any negative factor of using them as raw materials (Tab. 2).

The high phosphorous content of the Drymos sample is most likely attributed to the presence of Fe-Ca phosphates anapaite and mitridatite that have been described from the Sarantaporo-Elassona Basin, hosted in the diatomaceous groundmass, as well rounded or asymmetric nodules and fissure fillings [17].

2.1.4 SEM textural analyses

In order to identify the nature of the biogenic silica in the Greek samples, a component that is acting as flux agent during sintering, as well as the porosity and the pore shapes of the sintered products, scanning electron microscopy was used (Figs. 5, 6).

2.1.5 Thermal analyses

The thermal behaviour of the two materials has been studied up to 900 °C, the thermal effects and weight loss in this temperature interval has been recorded. Due to the fact that the oxidic composition of the two clays is similar, the two diagrams do not show significant differences. The interpretation of the observed thermal effects for Drymos sample is as follows (Fig. 7):

- In the 100 – 220 °C temperature range, the sample shows a strong endothermic effect accompanied by weight loss (about 3 %) as a result of the opal dehydration

Tab. 1 Chemical composition of the analyzed bulk samples from Drymos and Kleidi

Sample	Oxides [mass-%]									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	LOI	Total
Drymos	72,51	8,83	4,95	1,37	0,84	0,21	1	0,34	5,96	99,71
Kleidi	68,34	9,8	6,45	1,98	1,66	1,22	1,37	0,63	8,56	100,01

Tab. 2 Trace element content of the analyzed samples from Drymos and Kleidi

Sample	Unit	Drymos	Kleidi		Sample	Unit	Drymos	Kleidi
Ag	ppm	0,04	0,04		Ni	ppm	34	79,2
As	ppm	2,1	6,4		P	ppm	> 10 000	1470
Ba	ppm	610	550		Pb	ppm	22	20,1
Be	ppm	2,94	3,07		Rb	ppm	131,5	128
Bi	ppm	0,51	0,33		Re	ppm	< 0,002	< 0,002
Cd	ppm	0,18	0,25		S	%	0,04	0,13
Ce	ppm	77,2	65,5		Sb	ppm	0,2	0,46
Co	ppm	18,7	23,7		Sc	ppm	15,1	14,6
Cr	ppm	58	106		Se	ppm	2	2
Cs	ppm	5,2	5,34		Sn	ppm	2,1	2
Cu	ppm	31,5	34,5		Sr	ppm	152,5	234
Ga	ppm	22,4	21,2		Ta	ppm	1,07	1,23
Ge	ppm	8	0,08		Te	ppm	0,09	0,08
Hf	ppm	0,9	1		Th	ppm	15,6	13,3
Hg	ppm	0,05	0,04		Tl	ppm	0,71	0,89
In	ppm	0,065	0,054		U	ppm	7,4	3
Ln	ppm	0,074	0,052		V	ppm	102	113
La	ppm	37	33,3		W	ppm	8,2	8,4
Li	ppm	37,4	31,6		Y	ppm	30,3	30,5
Mn	ppm	959	1085		Zn	ppm	97	111
Mo	ppm	1,19	1,1		Zr	ppm	22,9	30,1
Nb	ppm	14,7	17,1					

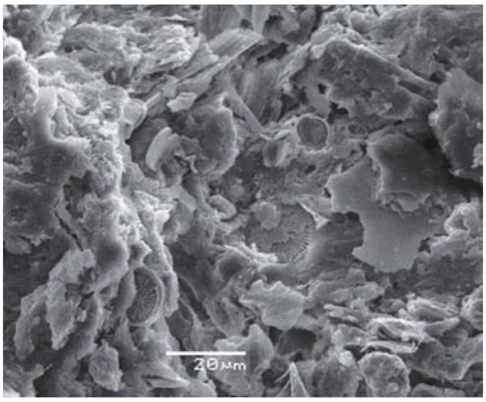

Fig. 5 Drymos deposit; disc-shaped diatom frustules hosted in a clayey matrix

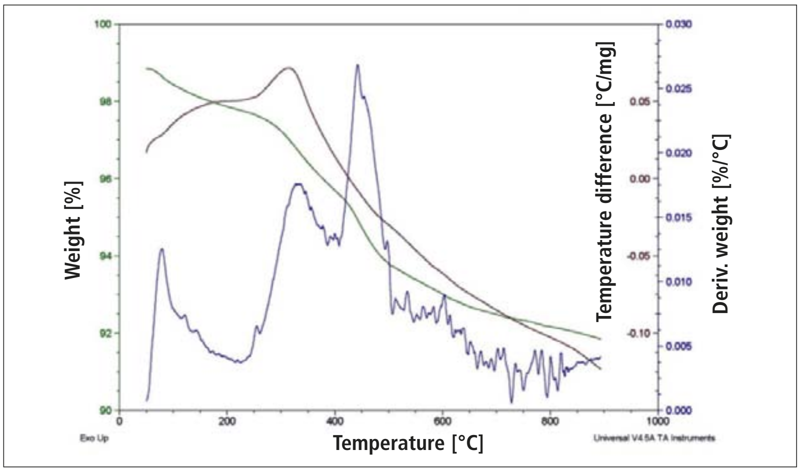

Fig. 8 Thermal behaviour (curves) for Kleidi sample

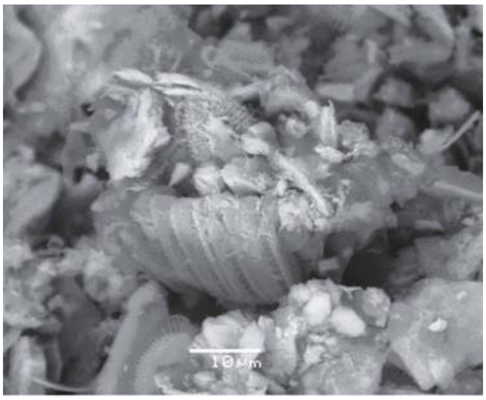

Fig. 6 Kleidi deposit; stacked, disc-shaped diatom frustules hosted in a clayey matrix

and loss of absorbed water in the clay minerals.

- At 220 – 560 °C an exothermic reaction occurred with a weak shoulder at about 460 °C and a weight loss of about 4,8 %. It is assumed that this is due to burnout of the organic matter, dehydroxilation of the clay minerals (loss of OH^- groups in illite/smectite occur until ~900 °C) and water loss from iron hydroxides. The small endothermic effect at 575 °C corresponds to the dehydroxilation of kaolinite.
- At 575 – 900 °C no significant thermal effects evidenced. The weight loss is about 3 %, mainly from dehydroxilation of clay minerals.

The interpretation of the observed thermal effects for the Kleidi sample is as follows (Fig. 8):

- In the 20 – 200 °C temperature range, the sample shows a strong endothermic effect accompanied by weight loss (about 2,5 %) as a result of the desorption and dehydration (removal of pore water and water adsorbed in the interlayer of the poorly crystallized clay minerals, i.e. illite/smectite).
- At 200 – 500 °C an exothermic reaction occurred with a weak about 400 °C and a large weight loss (about 7,5 %). It is assumed that this is due to burnout of the organic matter, dehydration of the clayey minerals (OH-loss in illite/smectite occurs until ~900 °C) and water loss from iron hydroxides.
- At 500 – 900 °C no significant thermal effects evidenced. Two small thermal effects, an exothermic effect at ~ 700 °C due to some oxidation processes of the elements (i.e. $Fe^{2+} \rightarrow Fe^{3+}$) and an endothermic one at ~ 900 °C because of the $CaCO_3$ decomposition from dolomite are present. The weight loss is about 2 %, mainly from decarbonation of dolomite and from dehydration of clayey minerals.

Thermal analysis represented the basis for establishing the firing diagram, by evidencing the processes related to temperature increase, which stop at about 900 °C. Accordingly, the maximum firing temperature (for the diatomitic raw material without additives) was established to be 900 °C.

2.1.6 IR spectroscopy

In both samples, the IR spectra are very similar (Fig. 9). A low, broad band due to the presence of OH^- groups in clay minerals (smectite, chlorite, illite) is present at 3400 – 3500 cm^{-1} and a small one specific for H-O-H vibration at 1630 cm^{-1}. The bands at 1035 – 800 cm^{-1} are assigned to Si-O and Al-O bonds in clay minerals.

The characteristic bands for quartz (Si-O-Si bounds) are found at 1090 cm^{-1} and for feldspar at 690 – 640 cm^{-1}. The 400 – 500 cm^{-1} band is connected by O-Me-O bonds vibration.

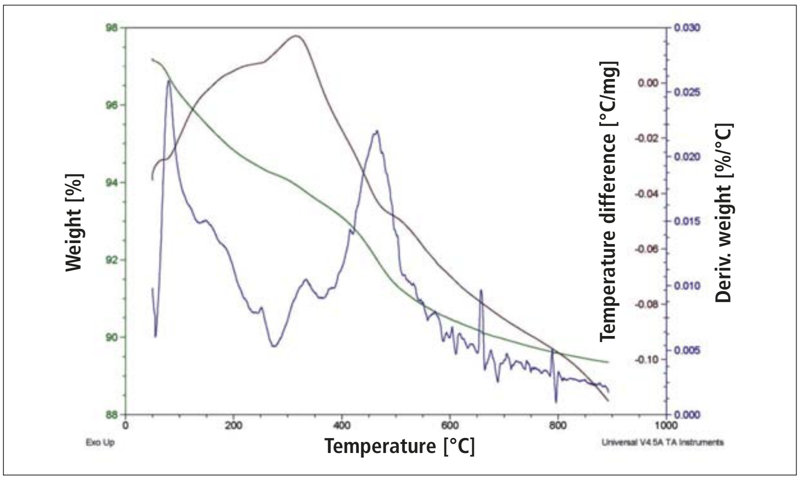

Fig. 7 Thermal behaviour (curves) for Drymos sample

2.2. Characterisation of sintered materials

2.2.1 Without additives

The pellets obtained from the raw materials were fired in a laboratory kiln for 12 – 15 min duration at different temperatures: 650, 700, 750, 800, 850, 900 and 950 °C, in order to obtain the best properties.

2.2.1.1 SEM images of the LWA's

The very low porosity in all samples from Kleidi and Drymos arises from the absence of sawdust during firing (Figs. 10–17). The samples have to be fired with sawdust at 900 °C and 1100 °C. The original minerals and mainly the opal-A will be destroyed, and the pellets will have a better strength.

2.2.1.2 Characterization of sintered products

In order to characterize the samples fired at different temperatures, compactness characteristics (absorption capacity, apparent density, apparent porosity) and compressive strength (on some specimens) were determined. The results are presented in Tab. 3.
The apparent porosity and the water absorption show similar values for the two samples, in the 50 – 55 % and respectively 40 – 50 % intervals.
The apparent density is < 1,2 g/cm³ (STAS) for the Drymos sample and relatively higher (up to 1,35 g/cm³) for Kleidi. From this point of view, the ceramic aggregates obtained from the Drymos raw material correspond to the standard values for light aggregates.
The compressive strength was tested on cylindrical moulds made of the samples fired at 650, 850 and 950 °C. As expected, a progressive increase of these values with temperature was noticed.
The mechanical strength parameters have shown higher values in the case of the use of Drymos material.

2.2.2 Lightweight aggregates

In the view of increasing the porosity of the ceramic aggregates and decreasing their apparent density, several mixtures were prepared from diatomite from Drymos and clayey diatomite from Kleidi with sawdust in various amounts: 1, 3, 5, 7 and 9 mass-%. The mixtures were prepared in wet state, they were mixed for homogenisation, and then they were formed as pellets < 3 cm in size, which were dried and then fired in laboratory ovens at temperatures of 900 and 1100 °C. The values measured for the compactness characteristics of the fired pellets are presented in Tab. 4.

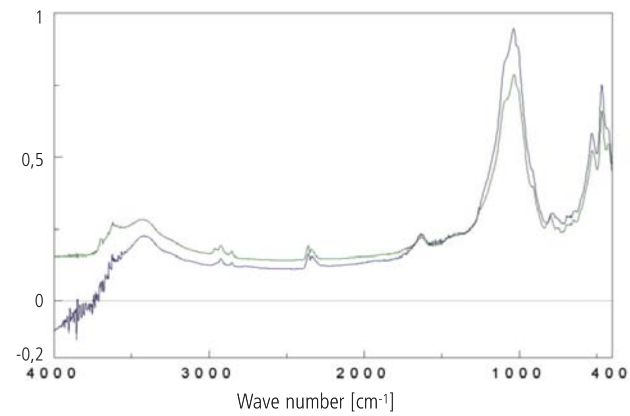

Fig. 9 **IR spectroscopy for raw materials Drymos – green line; Florina-Kleidi – blue line**

Tab. 3 **Compactness characteristics and compressive strength of the samples fired at different temperatures (no burnable material added)**

Temperature	Absorption capacity [%]		Apparent density [g/cm³]		Apparent porosity [%]		Compressive strength σ_{rc} [N/mm²]	
	Drymos	Kleidi	Drymos	Kleidi	Drymos	Kleidi	Drymos	Kleidi
650 °C	45,33	46,19	1,17	1,3	53,17	59,16	1,91	1,78
700 °C	46,64	45,47	1,16	1,21	51,91	54,88		
750 °C	45,87	46,09	1,17	1,2	53,49	55,27		
800 °C	46,12	38,52	1,17	1,31	54	50,3		
850 °C	46,82	38,82	1,13	1,3	54,36	50,6	2,67	2,49
900 °C	50,17	43,46	1,1	1,22	55,34	53,19		
950 °C	42,73	36,33	1,21	1,35	51,63	49,01	4,46	2,03

Tab. 4 **Compactness characteristics of the samples fired at 900 °C and 1100 °C (different percentage of burnable material added)**

Sawdust		Absorption capacity [%]		Apparent density [g/cm³]		Apparent porosity [%]	
	Sample	900 °C	1100 °C	900 °C	1100 °C	900 °C	1100 °C
1 %	Drymos	55,84	6,47	1,03	2,07	57,63	13,39
	Kleidi	50,11	14,55	1,13	1,88	56,76	18,04
3 %	Drymos	56,51	18,76	1,07	1,7	58,49	31,76
	Kleidi	59,88	12,6	1,02	1,95	61,19	24,5
5 %	Drymos	65,18	16,27	1,02	1,75	59,3	28,3
	Kleidi	59,08	13,1	1,03	1,92	60,75	25,08
7 %	Drymos	71,52		0,88		62,94	
	Kleidi	67,36		0,95		63,86	
9 %	Drymos	77,74		0,84		64,99	
	Kleidi	68,8		0,93		64,12	

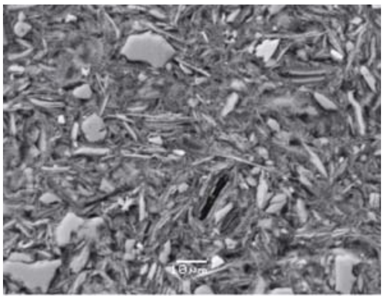

Fig. 10 **Drymos sample, calcined at 650 °C**

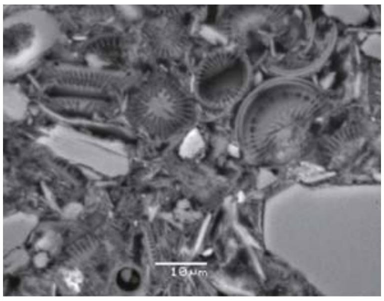

Fig. 11 **Drymos sample, calcined at 750 °C; no intense dissolution, the diatom frustules are preserved**

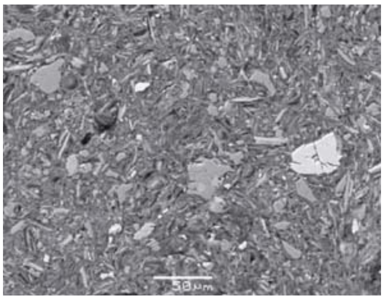

Fig. 12 **Drymos sample, calcined at 850 °C; the diatom frustules are still preserved, in some samples slight dissol-ution has been detected**

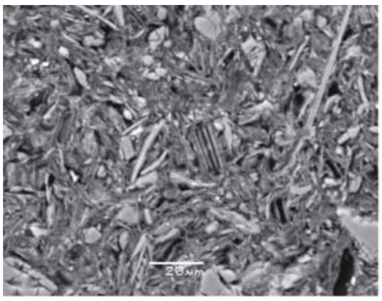

Fig. 13 **Drymos sample, calcined at 950 °C; no diatom frustules are visible**

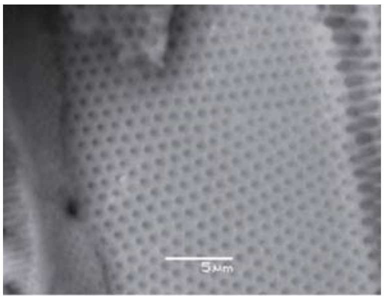

Fig. 14 **Florina-Kleidi sample, fired at 650 °C; similarly to Drymos, its biogenic silica dissolution is negligible, the diatom frustules persist**

Fig. 15 **Florina-Kleidi sample, fired at 750 °C; fragments of the detrital minerals are visible (feldspar, quartz), clayey fine-grained matrix also; the diatom frustules are also well preserved, no intense mineral transformation**

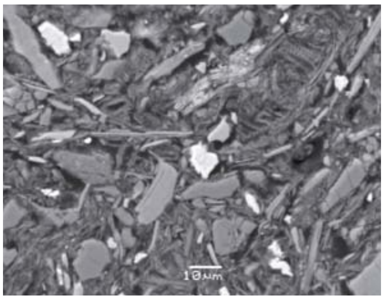

Fig. 16 **Florina-Kleidi sample, fired at 850 °C; the diatom frustules are preserved, the bright spots are mainly sphene TiO_2; the other phyllosilicates are mainly muscovite**

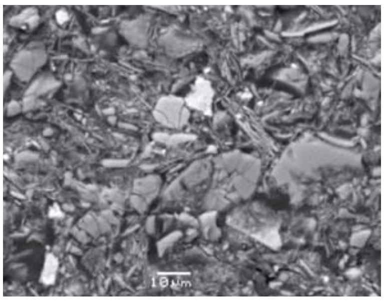

Fig. 17 **Sample from Florina-Kleidi, fired at 950 °C; no diatom frustules are visible**

2.2.2.1 Compactness characteristics

Based on the high values for porosity and density in samples using 1, 3 and 5 % sawdust fired at 1100 °C, for the samples mixed with 7 and 9 % sawdust the thermal tests were carried out only at 900 °C.
For the samples fired at 1100 °C, one can notice the increase of the apparent porosity of the aggregates (up to ~65 %) and a decrease of density (< 1 %) in direct correlation with the concentration of sawdust (Tab. 4). The samples fired at 1100 °C show an incipient sintering, accompanied by a pronounced decrease of porosity (from 13 to 25 %) for sawdust additions of 1 – 5 %, while the apparent density is about 2 %. The samples with densities below 1,2 g/cm³ and high porosity comply with the requirements of porous lightweight aggregates.

2.2.2.2 Thermal conductivity of the aggregates

Thermal conductivity was measured on aggregates containing 7 and 9 % sawdust, by using a HFM 3 Lambda unit with a mould suitable for granular materials. The ceramic grains < 5 mm in size were measured under a thermal gradient of 20 °C (temperature of the lower plate of 0 °C and that of the upper plate of 20 °C). The results are presented in Tab. 5. The thermal conductivity of the analysed samples decreases with increasing the sawdust concentration. The values comply with the standard values for ceramic aggregates (0,11 W/m · K).

2.2.2.3 Compressive strength of the fired clays

The samples with 7 and respectively 9 mass-% sawdust have been tested for their mechanical resistance to compression; the results are presented in Tab. 6.
In both cases, the aggregates containing Drymos raw material show a higher – almost double – mechanical strength as compared to those using Kleidi raw material. This could be explained by sintering processes occurring in the ceramic aggregates with Drymos raw material due to the presence of Fe-Ca phosphates that build-up strong bondings between SiO_2 grains.

3 Tests for concrete mixtures (lightweight concrete LWC)

The ceramic aggregates of the two raw materials mixed with 7 and 9 mass-% sawdust

Tab. 5 Thermal behaviour of aggregates containing 7 and 9 mass-% sawdust

Sample	Sawdust	Thermal conductivity [W/m · K]	Thermal resistance [m² · K/W]
Drymos	7 %	0,115019	0,272182
Kleidi		0,116192	0,252882
Drymos	9 %	0,11194	0,271565
Kleidi		0,102425	0,283856

Tab. 6 Compressive strength of the fired clays (7 and 9 % sawdust)

Sawdust	Sample	Compressive strength [N/mm²]
7 %	Drymos	1,3393
	Kleidi	0,6507
9 %	Drymos	1,0516
	Kleidi	0,5989

Tab. 7 Mechanical properties of the concrete moulds (with aggregates from the two raw materials mixed with 7 and 9 % sawdust)

	Density [kg/m³]	Bending strength [N/mm²]	Compressive strength [N/mm²]
LWC with Drymos 7 %	1513	4,2187	18,39
LWC with Drymos 9 %	1445	3,8671	16,75
LWC with Kleidi 7 %	1660	2,6953	10,16
LWC with Kleidi 9 %	1611,5	2,2265	7,79

have been tested in concrete compositions with a cement : aggregate ratio of 1 : 3.
For obtaining the ceramic aggregate, before forming the previously dried mixture is poured into refractory capsules and thermally treated at 900 °C with a 90 min duration. After firing, the aggregates are crushed to maximum sizes of 3 mm and then mixed with the corresponding ratios of cement and water, required for obtaining a paste with good workability. The mixture is homogenized and poured into prismatic shapes. After 24 h the material is removed from the moulds and then preserved in a humid environment. The apparent density and mechanical strength parameters are tested after 28 d. The results are presented in Tab. 7.

3.1 Density, bending and compressive strength of the concrete moulds

The mechanical properties of concrete, i.e. both the bending and the compressive strength are influenced by the mechanical resistance of the ceramic aggregate (Tab. 7). It can be noticed that the strength of the concrete increases when 7 % sawdust is added, while it decreases when 9 % sawdust is added – in the case of both raw materials. The strength values are higher – almost double – in case of the samples with Drymos raw material.

4 Conclusions

Investigating the Greek clay-rich samples showed that the raw materials are clayey materials of sedimentary origin containing appreciable amounts of biogenic silica (15 – 30 % opal-A), with the form of diatom frustules. These rocks are overburden of mostly exploitable lignite deposits located in central and northern Greece.
The deposits examined are those of Kleidi, Amynteo Florina (new lignite quarry) and Drymos Sarantaporo-Elassona that is mostly a clayey formation hosting only thin, non-exploited lignite seams.
Several samples were measured by XRD (mineralogy), SEM (texture, mineralogy) and XRF (chemistry).
Two samples out of 5 bulk samples were completely tested and characterized. These samples were also used to produce lightweight aggregates (LWA) and lightweight concrete (LWC).
Using the raw (powdered) samples burned at 850 – 950 °C specimens with very good compressive strength and apparent density parameters were achieved.
In order to obtain LWA with a higher porosity, sawdust was added to the raw clayey material. Regarding the proportion of combustible material (sawdust) as part of the mixture, 1, 3, 5, 7, 9 mass-% addition in the mixture was tested to obtain a good combination of compressive strength and low weight.
Adding sawdust decreased the mechanical strength; however, the parameters complied with those required for light aggregates. The mechanichal strength of the Drymos sample is higher than that of the Kleidi sample due to the presence of Fe-CA phosphates, which at high temperatures act as a flux, generating the necessary melt for binding solid particles.
In the case of aggregates used for concrete, thermal conductivity represents an important feature. In the case of samples mixed with 7 and 9 mass-% sawdust, the values comply with those imposed by the European standards. The mechanical resistance of the aggregates influences the resistance of light concrete, in a direct correlation.

5 Possibilities of economic use

Tested clayey rocks from Greece mixed with burnable matter can be pelletized and expanded to form lightweight aggregates. The results obtained regarding a good combination of compressive strength and apparent density could be improved. The samples with a low apparent density and a low compressive strength could be used as hydroponics, herbicide and fertilizer carriers, decorative ground. The preliminary results show that the clayey rocks could be used to produce lightweight aggregates. LWAs are used in mixtures with cement to produce lightweight and insulation concrete (LWC), (ceramic porous or refractory) blocks of various sizes, as loose insulation fills in walls and floors and in geo-technical and environmental applications.

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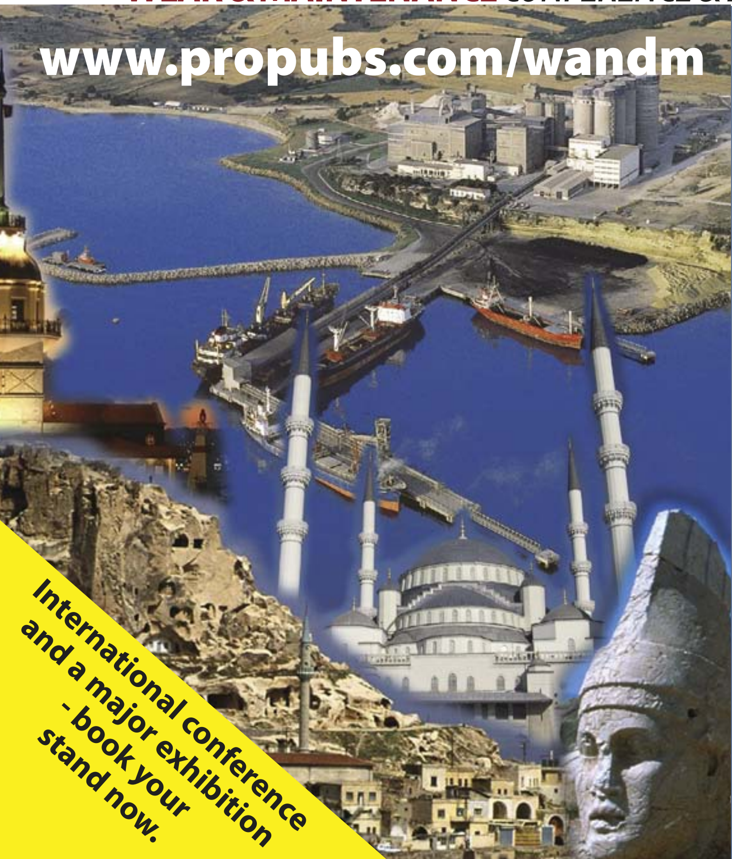

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