Pyro-expanded black slate in sculptural art

(Ardósia piroexpandida em arte escultórica)

***J. C. e Costa*[1]*, T. Almeida*[2]*, C. S. F. Gomes*[3]**

[1]PhD student in the Faculty of fine arts of the University of Porto (FBAUP) and researcher at the i2ADS (Institute for Research in Art, Design and Society), 4000 - Porto, Portugal
joaocunhaecosta@hotmail.com

[2]Lecturer in FBAUP and researcher of the VICARTE (Research Unit for the Glass and Ceramics Arts) FCT\UNL, Campus Universitário da Caparica, Caparica, Portugal 2829-516
teresalmeida@gmail.com

[3]Full Professor (retired) and researcher of the Research Unit GeoBioTec of FCT (Foundation for Science and Technology), University of Aveiro, Aveiro, Portugal 3810-193
cgomes@ua.pt

Abstract

Black slate transformed through a pyroplastic process named pyro-expansion or exfoliation has been explored in the present work in order to be used as sculptural material. Black slate is a highly fissile, fine grained and organic matter rich rock that is the product of the action of low-grade regional metamorphism on black shale (a sedimentary clay and organic matter rich, also fissile and fine grained rock). Black slate if fired at an adequate firing rate up to the temperature range 1000 ºC-1240 ºC shows great potential for the manufacture of sculptural pieces. The technical possibilities of the shaping or conformation of pyro-expanded black slate have also been studied, including the reactions that take place when two different black slate pieces are closely associated with each other, or when black slate pieces are closely associated to other materials, such as metals and ceramics. These interactions, while associating different materials that react with each other, emphasize the unique characteristics of new sculptural compositions increasing the plastic capacities of the pyro-expanded black slate. Some examples of the associations referred to will be shown, which highlight the close functional relationship between art and science; research involves the approach to new techniques and materials, looking at the development of unique plastic configurations.
Keywords: black slate, pyroplastic expansion, exfoliation, sculptural art, geology, ceramics.

Resumo

No presente artigo são divulgados os resultados da investigação do comportamento para fins escultóricos da ardósia (rocha de cor negra, granularidade fina e clivagem fina que resulta da acção de metamorfismo regional de baixo grau sobre rocha sedimentar, argilito laminado rico em matéria orgânica) transformada piroplasticamente. O material resultante é denominado ardósia piro-expandida ou exfoliada, depois da ardósia natural ser tratada termicamente a temperaturas até 1000 °C-1240 ºC. A investigação subjacente fez uso e desenvolveu conhecimentos do domínio da geologia, mais especificamente dos materiais geológicos, aplicando-os à escultura e procurando responder aos objectivos e requisitos desta arte. São divulgadas, também, as possibilidades técnicas de conformação dependentes das interacções que acontecem no decorrer do processo piroplástico, quer entre diferentes elementos de ardósia, quer entre elementos de ardósia e elementos de metal ou, ainda, entre elementos de ardósia e elementos de cerâmica. Estas interacções, ao associarem elementos distintos, naturalmente com respostas térmicas distintas, condicionam a conformação conjunta do sistema selecionado e enfatizam a singularidade da composição escultórica resultante, alargando consideravelmente as capacidades plásticas (no sentido artístico) da ardósia. São apresentados alguns exemplos destas composições escultóricas que evidenciam a relação científica e funcional entre arte e ciência.
Palavras-chave*: ardósia, expansão piroplástica, exfoliação, arte escultórica, geologia, cerâmicas.*

INTRODUCTION

The main goal of the present paper is the pyro-expansion of black slate while material used in sculpture, and the accomplishment of this desideratum involves the double crossing of fundamental information provided by the scientific fields of geology and materials science with concepts and practices of the fields of art and sculpture.

In fact the pyroplastic process to which the black slate is submitted is similar to the ordinary ceramic process. If properly fired the black slate initial volume can expand four times, becoming transformed into a new and distinct material in terms of composition (mineral and chemical), structure and color (Fig. 1).

The behavior of black slate pyro-expansion is expressed itself in a language that tells us its own identity and narrative in an objective and explicit way, and with an intense expressiveness that surprises ourselves.

Figure 1: Black slate piece at room temperature (A) with dimensions 21 cm x 13.5 cm x 3 cm and after pyroplastic expansion up to 1200 °C (B) with dimensions 22 cm x 13.5 cm x 12 cm.
[Figura 1: Peça de ardósia preta na temperatura ambiente (A) com dimensões 21 cm x 13,5 cm x 3 cm e após a expansão pyroplástica até 1200 °C (B) com dimensões 22 cm x 13,5 cm x 12 cm.]

Pyro-expanded black slate as an industrial material is basically considered to belong to the category of light aggregates, materials used in the production of light concrete structures, category into which pyro-expanded materials, such as clay, clay shale, vermiculite, perlite and others are classified. These materials are also used as soil composing elements in gardens, filling materials in building construction, thermal and acoustic insulation materials, and as water filtering materials.

Research knowledge and development of light aggregates manufacture begun in 1908 and was patented in the US, in 1918. Their pyroplastic transformation takes place in rotative kilns at temperatures above 1000 ºC [1]. Besides the specific characteristics of pyro-expanded black slate which allow for different applications, we highlight its expressive potentialities and hold it as a material with good qualities for sculpture work. The use of this material in sculpture has been very incipient up to the present, and we do not know any written record describing the specific technical procedures of the respective pyroplastic process. This paper and the research we are carrying out responds to the absence of the information referred to. In fact this paper describes the way black slate behaves when fired to temperatures up to 1000 ºC-1240 ºC. It also describes different technical possibilities of pyro-expanded black slate shaping or conformation taking advantage of the interactions of the association of different black slate elements and of the association of black slate elements with ceramics or metal elements.

MATERIALS AND METHODS

Black slate is a rock that results from the action of regional metamorphism of low-grade, and is characterized by fine granularity, fine lamination, low density, soft touch, and black or dark gray color. The starting geological material is a laminated clay or shale rich in organic matter and in clay minerals (fine grained hydrous phyllosilicates). These phyllosilicates are responsible by the original fine lamination that persists and is enhanced after pyro-expansion.

The main chemical components of black slates are currently determined using XRF (X-ray Fluorescence): SiO_2 (52%-60%), Al_2O_3 (20%-25%) and Fe_2O_3 + FeO (6%-10%). FeO content corresponding to iron in the reduced form Fe^{2+} is dominant relatively to Fe_2O_3 content, corresponding to iron in the oxidize form Fe^{3+}. Carbon (C) and sulfur (S) are also significant components of the black slates. The black slate being investigated was supplied by an enterprise involved in quarrying and processing works of black slate, and whose activities are located in Campo, Valongo (northwest Portugal). The average chemical composition of Valongo black slate being used in the experiences we had carried out are disclosed in the present paper as follows: SiO_2-53.3%, Al_2O_3-24.03%, Fe_2O_3 + FeO-8.79%, K_2O-3.06, MgO-2.08%. Small quantities of other elements are also present. Also it contains 4.47 % (in weight) of carbon and 5.12% of L.I. (loss on ignition), the last value corresponding to the gaseous evolution of volatile constituents, water vapor, CO_2 and SO_3 [2].

The aforementioned investigation was carried out at the Fine Arts Faculty of the Universidade do Porto having sculpture design and production as its main goal and scope. The Faculty has several electric kilns with digital thermostats to fire and produce ceramic pieces; therefore, the results of the firing process are the simple cross control of the indicated temperatures with the physical/sensorial record. The lack of scientific experience is compensated by the pertinence in what sculptural accomplishment is concerned.

Black slate thermal expansion is the result of gases formation - CO_2, SO_3 and H_2O - accumulated in gas pockets, gases which are derived from the decomposition of organic matter, hydrous fine grained phyllosilicates (clay minerals, such as illite, kaolinite, chlorite, here referred by decreasing content), and chloritoids, muscovite, pyrite, gypsum, calcite, dolomite, goethite and hematite. Some of the evolved gases could become sealed inside the inorganic mass constituting the fired black slate piece [3]. Iron oxidation itself, from Fe^{2+} to Fe^{3+}, during the ceramic process, contributes although in less degree, for the thermal expansion. The fundamental reactions that promote black slate expansion take place within the temperature range 400 ºC-800 ºC, and essentially consist of the aforementioned evolved gases; from 800 ºC onwards the vitrification phase is initiated and progressively developed, resulting in the formation of an essentially alkaline alumino-silicate glass that provides gas retention in the most internal parts of black slate pieces [4]. Despite gases liberation taking place at temperatures less than 800 ºC, black slate expansion increases up to 1050 ºC-1150 ºC, being the highest when temperature reaches the maximum temperature value. As far as temperature increases and provides gases dilatation, this gas phase presses the glassy material that acquires and develops plasticity and elasticity. Gases can migrate up to the external surfaces of the pyro-expanded black slate pieces and escape to the kiln atmosphere. The created porous structures can be observed at the microscope. Fig. 2 shows one scanning electron micrograph of pyro-expanded black slate from Valongo fired at 1180 ºC. SEM studies were carried out at the Laboratory of Electron Microscopy, in the Department of Materials Science of the University of Aveiro, using one Hitachi equipment, model S4100 and micro-analyzed by Energy Dispersive Spectroscopy (EDS).

Black slate submission to procedures proper of the ceramics firing facilitates the integration of expanded and exfoliated black slate within the practices of artistic ceramics. In fact, the investigation being carried out took into account the current practices of the ceramic process, that is, the black slate was submitted to the heating conditions proper of ceramic firing in electric kilns.

In the adopted firing cycle, the thermal gradient was 100 ºC/h up to the temperature of 300 ºC being reached; afterwards the thermal gradient was increased on a constant rate till the maximum firing temperature being attained, and soaking took place during 10 min. Temperature increase from 300 ºC up to 1000 ºC did last about 3 h, and from 1000 ºC to 1240 ºC did last 2 h (Fig. 3).

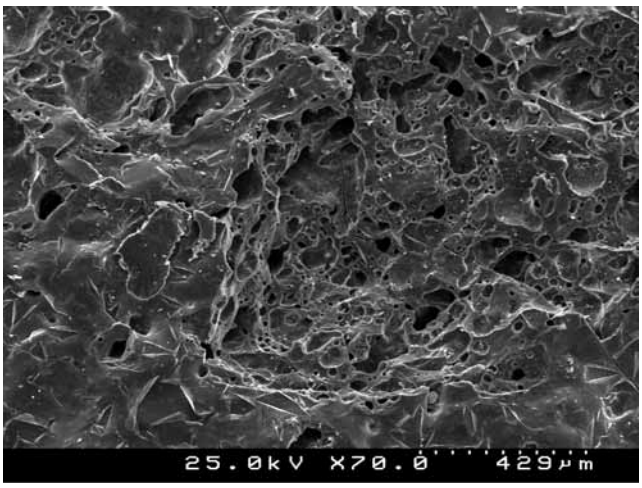

Figure 2: Scanning electron microscopy micrograph of a fracture surface of the Valongo black slate fired at 1180 ºC.
[Figura 2: Micrografia de microscopia eletrônica de varredura de uma superfície de fratura de ardósia preta de Valongo submetida a 1180 ºC.]

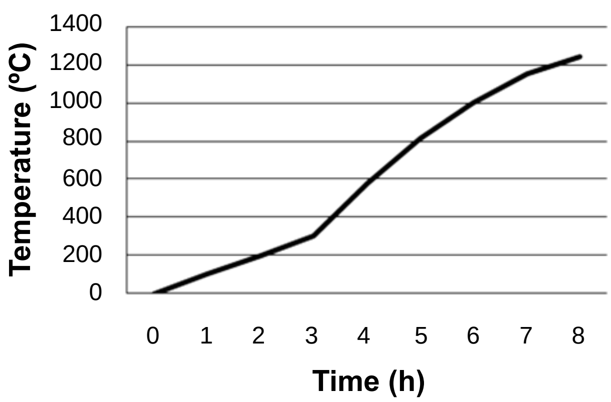

Figure 3: Heating curve of the adopted firing cycle.
[Figura 3: Curva de aquecimento do ciclo de cozedura adotado.]

RESULTS AND DISCUSSION

Two of the most significant factors involved in the process of black slate pyro-expansion have been studied: 1) the temperature at which the slate is submitted, named slate free pyroplastic expansion; 2) the constraints caused by both interactions between different elements of slate and between these elements and ceramic or metal elements, named slate constrained pyroplastic expansion.

Free pyroplastic expansion

Black slate behavior when subjected to high temperatures exposes some variation, because the slate does not always have the same composition or a quite similar structure and, however, there is a strong degree of proximity of results.

When black slate is submitted to temperatures over 1050 ºC expansion takes place, and the overlapping fine structural blades proper of this type of rock, become separated from each other, but without being individualized (Fig. 4). Black slate expansion takes place and increases as far as the individual blades of the original piece get far off, that is, assuming an initial parallelepiped shape, the opposed faces parallel to lamination, and apparently constituted by one thick blade alone, will not exhibit significant changes of area during firing, whereas the four other faces perpendicular to lamination, showing the fine slate lamination, increase in area up to four times, approximately.

After firing at 1000 ºC, the color of the black slate changes from black to rose and rusty-red, but the fired

Figure 4: Black slate fired up to 1050 °C; dimensions 25 cm x 21 cm x 3 cm.
[Figura 4: Ardósia preta submetida a 1050 °C; dimensões 25 cm x 21 cm x 3 cm.]

piece keeps its shape. At 1080 ºC the black slate piece can expand 100% or even more depending upon how the black slate piece is positioned inside the kiln, since in case the black slate piece lies down on a face perpendicular to the lamination, expansion amplitude is higher than when the piece lies down on a face parallel to the lamination.

After firing, the black slate piece approximately maintains the initial shape. For instance, if the initial shape is parallelepiped the shape is more or less maintained, in spite of the thickness increase proportional to dilatation. Increasing the firing temperature the black slate piece becomes darker and maintains the rusty-red color, but gains in gloss and shows a silky sheen due to the parallel orientation of the very fine grained philosilicates minerals. On the external faces pimples are developed making the texture of these surfaces looking like the bark of some trees (Fig. 5). The internal structure of the piece persists but the overlapping blades lose their original perfect connection, whereas their hardness and mechanical resistance increase. The relationship between volume and weight is proportional to dilatation, the original material changes to a less dense and light material.

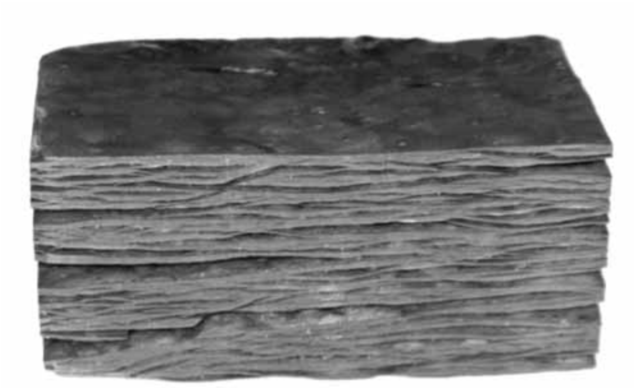

Figure 5: Black slate fired up to 1100 °C; dimensions 16 cm x 7 cm x 8.5 cm.

[Figura 5: Ardósia preta submetida a 1100 °C; dimensões 16 cm x 7 cm x 8,5 cm.]

At 1150 ºC the piece shape initiates a radical transformation expressed by bending. The piece texture looking like the bark of a tree gets thinner and dense and the shape of the final product is quite different from the original shape. Also, in terms of internal structure made of overlapped blades, it changes to a spongy structure that is observed from 1130 ºC on, although keeping mainly a vestigial skin of the precedent structure. The surface of this skin shows a more uniform gloss reminding the gloss of the leather, and its relief is accentuated. This skin shows ragged areas with peepholes through which peeps and overflows the characteristic spongy interior (Fig. 6). The most internal zone of this spongy structure exhibits black color, and as far as it gets close to the surface changes to grey, and to light red very close to the surface. These color changes indicate either the easy access or difficult access of oxygen during firing.

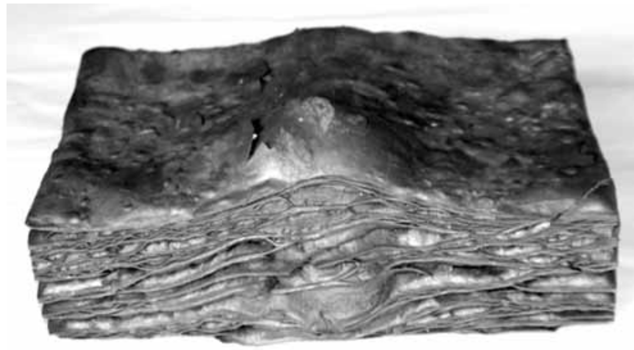

Figure 6: Black slate fired up to 1150 °C; dimensions 26.5 cm x 21 cm x 11 cm.

[Figura 6: Ardósia preta submetida a 1150 °C; dimensões 26,5 cm x 21 cm x 11 cm.]

The black slate did lose some hardness and mechanical resistance becoming fragile and brittle, but acquires a very expressive telluric character, reflecting the intensity and impetuosity of the ceramic firing process (Fig. 6). Slate has changed into a lighter material than when it was fired at 1100 ºC. At 1150 ºC the pieces of pyro-expanded black slate, in case they are put in contact, become bond to each other, and they could weld to iron or ceramic elements or objects. Hence, when black slate pieces are placed inside the kiln it is important to separate or isolate the bases of black slate pieces from the kiln floor. If fired at 1150 ºC or at higher temperatures, black slate changes into a material easy to saw.

Fired at 1240 ºC the proper structure of the slate blades starts to split and their skin is ripped apart showing the sandy and porous texture of its internal fully spongy mass. The shape change that takes place is still more radical and unforeseen (Fig. 7), but the black slate recovers hardness and mechanical resistance.

Figure 7: Black slate fired up to 1240 °C; dimensions 12 cm x 10 cm x 8.5 cm.

[Figura 7: Ardósia preta submetida a 1240 °C; dimensões 12 cm x 10 cm x 8,5 cm.]

Comparing the obtained results with the results obtained after firing at 1150 ºC, volumes are approximately the same, that is, maximum dilatation essentially happens at 1150 ºC or even at slightly lower temperature. Also, the relationship between volume and weight do not substantially changes in the temperature range 1150 ºC-1240 ºC. If different black slate pieces being in contact are fired at 1240 ºC, due to vitrification they become firmly welded to each other or to metal or ceramic pieces.

The initial compact volume of the black slate piece is progressively lost, becoming expanded and opening up its interior; it will be difficult to recognize the initial piece aspect, volume and shape.

Black slate expansion amplitude is primarily correlated with the firing maximum temperature as well as with the dimension of the tested pieces. Factors such as mass and weight (this factor depends on piece positioning) influence expansion amplitude. The effects of both temperature factor and dimension factor require further and thorough investigation in order to be better understood.

Constrained pyroplastic expansion

Expansion during firing allows black slate elements to interact between themselves, in terms of shaping process; this may happen in two different ways - assemblies (1) and mortises (2).

(1) Assemblies are based on the fact that black slate pieces stick together, in case they are in contact during firing; they stick more strongly if the contact is strengthened by some kind of pressure, such as the weight of an element on the other. Black slate pieces can expand and stick together in just one firing (Fig. 8) or they can be expanded previously, and later submitted to a second firing for pieces assemblage. This latter option allows composing in a more safe way, since the second fire doesn't imply a radical change in volume or shape.

Figure 8: Pyro-expanded black slate fired up to 1160 ºC; dimensions 19 cm x 15 cm x 15 cm.
[Figura 8: Ardósia preta piro-expandida a 1160 ºC; dimensões 19 cm x 15 cm x 15 cm.]

The assemblies can integrate elements of other materials showing good refractory characteristics, such as ceramics or metals that could become bonded to the pyro-expanded black slate when brought into contact with it.

(2) – The mortises of a black slate piece in another one are carried out by cutting an entrance in one piece or in both pieces; the cut width must be related to the thickness of the piece to be incased; in mortises adjacent areas, expansion is mutually constrained, providing rich expressiveness (Fig. 9).

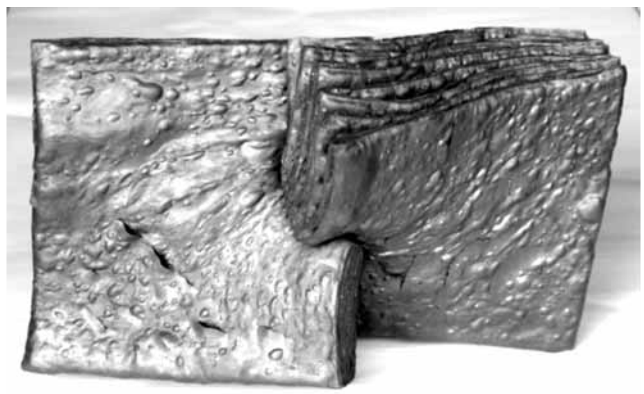

Figure 9: Pyro-expanded black slate fired up to 1200 ºC; dimensions 36 cm x 23 cm x 15 cm.
[Figura 9: Ardósia preta piro-expandida a 1200 ºC; dimensões 36 cm x 23 cm x 15 cm.]

In what the participation of ceramics elements is concerned, three types of relations between pyro-expanded black slate elements and ceramic elements have been explored; ceramic elements with the function of molding the shape of pyro-expanded black slate elements (3); black slate elements incased in ceramic containers and expanded afterwards (4); and black slate elements stuck into ceramics elements and then expanded (5).

(3) - At 1150 ºC black slate has already attained its maximum expansion acquiring the shape of its supporting surface, and ceramic molds covered with a separator can be used in pyro-expanded slate shaping process.

(4) - A black slate piece partially placed inside a ceramics container having its expansion partially limited by both size and available internal space of the ceramic container space; since part of the black slate piece stays out of the container it fully expands, and most probably falls and folds down; in this situation both ceramic container and black slate pieces stick together (Fig. 10).

(5) - If black slate pieces are stuck to a ceramic wet body, in case this is moist enough to present some degree of plasticity, the incased parts hardly expand, but again the outer parts freely expand; the ceramic body must be thick enough to support the pressure exerted by the slate during the pyro-expansion process.

With regard to the participation of iron elements, the relation that pyro-expanded black slate elements and iron

Figure 10: Assemblage of ceramic and pyro-expanded black slate fired up to 1240 ºC; dimensions 14.5 cm x 16 cm x 18 cm.
[Figura 10: Montagem de cerâmica e ardósia preta piro-expandida a 1240 ºC; dimensões 14,5 cm x 16 cm x 18 cm.]

elements fired together establish between themselves is marked by the type of iron element that is used; two types of relations between iron and pyro-expanded black slate elements are presented: screws with the respective nuts (6), and wire (7).

(6) - The screw and the respective nut condition and limit the expansion of black slate elements, providing an effect similar to "button that presses the center of the cushion".

(7) - A wire piece, 2.5 mm thick, placed all around the parallelepiped black slate, provides a "belting" effect (Fig. 11); black slate expansion has pressed and strained the iron wire, configuring in this case a mutual shaping.

Figure 11: Assemblage of iron wire and pyro-expanded black slate fired up to 1220 ºC; dimensions 14 cm x 12 cm x 9 cm.
[Figura 11: Montagem de arame de ferro e ardósia preta pyro-expandida a 1220 ºC; dimensões 14 cm x 12 cm x 9 cm.]

The possibilities of interactions presented here are a not exhaustive survey of elementary solutions that combined make possible an increasing complexity and sophistication of the pyro-expanded slate sculptural work.

CONCLUSIONS

The pyro-expanded black slate provides evidence of both original structure and geologic formation, and shows its migrating identity, since a natural stone has changed into a ceramic material. Its acquired structure gets close to the structure exhibited by some pyroclastic volcanic rocks, as pumice, that bear gas pockets, fact that confers to them floating capacity in water. The technical process involved in black slate pyroplastic exfoliation, the refractoriness being acquired, and its chemical composition indicate that the pyro-expanded slate is a ceramic material. The existence of iron is fundamental for the transformation process, since it condition black slate fusion temperature, diminishing it, and causing the metallic aspect exhibited by their surfaces. Pyro-expanded black slate clarifies in a surprisingly way the relationships between stone, ceramics and iron, in natural context. The configuration of the sculptural products based on pyro-expanded black slate depends upon the following factors: 1. experience and artistic sensibility of the sculptor; 2. mineralogical and chemical specificities; 3. lamination degree (fine or coarse) specificities; 4. thermal process specificities (maximum firing temperature, firing rhythm, and more or less oxidizing firing atmosphere); 5. initial configuration of black slate pieces; 6. in composite pieces (for instance, black slate-metal, black slate-ceramics) the associated metal or ceramic pieces could locally constraint black slate expansibility. Finally the aspect of both external and internal surfaces of the sculptural products based on pyro-expanded black slate, which is expressed by varied red dyes and by more or less silky textures, depends upon the specificities of the initial black slate and upon the specificities of the thermal treatment. The research and work being carried out shows that the pyro-expanded black slate is a geomaterial characterized for its sculptoric vocation, due to its capability and expressive richness, identifiable with its telluric and unforseen nature, violent, savage, and primeval. The uncertainity of its final conformation do not recommends black slate as design material for precisely shaped goods; however, it can be used as raw material for the manufacture of objects not requiring a precise shape, otherwise a strong expression according to the characteristics of the exfoliated or pyro-expanded black slate. One of the emerging trends in the panorama of contemporary art is the notorious increment verified in the relationship between art and science; more and more art works are based on scientific information and processes [5-7], the herewith disclosed research being a good example of such.

REFERENCES

[1] http://www.escsi.org/uploadedFiles/Technical_Docs/General_Information/7600.1%20Lightweight%20Ag, in http://www.escsi.org, (site of Expanded shale, clay and slate Institute), consulted on 10/10/2010, p. 5.
[2] L. M. G Catarino, "Xistos ardosíferos - caracterização e recuperação de desperdícios", Tese Dr., Faculdade

de Ciências e Tecnologia da Universidade de Coimbra, Coimbra, Portugal (1999) p 69**.**
[3] C. S. F. Gomes, *Argilas Aplicações na Indústria*, Ed. Universidade de Aveiro, Aveiro, Portugal (2002) p 214**.**
[4] A. C. Moura, J. Grade, "Contribuição para o estudo de xistos ardosíferos de Valongo", in Estudos, Notas e Trabalhos S. F. M., **XXIII**, 3-4 (1977) p 257.
[5] S. Wilson, *"Information arts - Intersections of art, science and technology",* Ed. The MIT Press, Cambridge - Mass, USA (2002) p. 3.
[6] S. Ede, *"Art & Science"*, Ed. I. B.Taurus, Great Britain (2005) p. 2.
[7] J. F. Laiglesia, J. Loeck, M. R. Caeiro, *La cultura transversal - Colaboraciones entre arte, ciencia e tecnologia*; Ed. Universidade de Vigo, Vigo, Spain (2010).
(Rec. 12/06/2012, Ac. 08/06/2012)