Hontoria's stone (Burgos, Spain) Characteristics and weathering

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Abstract

This paper deals with petrological and petrophysical features of the Hontoria's stone, Burgos (Spain), with which many important monuments were built in northern Spain, in order to establish a basis for individual monument restoration.

The study contains an historical reference to some buildings in which this stone was employed, geological considerations of the origin area, laboratory analysis of the samples, and results of the most common characterization tests.

As a conclusion, it can be stated that the Hontoria's stone is a pure limestone, with good mechanical and hydrological behaviour, resistent to weathering, easy to quarry (underground mining) and with large resources.

Keywords

Limestone, petrology, mechanical properties, castilla-león, weathering.

Introduction

The aim of this paper is to acquire the maximum knowledge about Hontoria's stone and its characterization. This variety of limestone has been used in many Spanish monuments, some of them of such importance as the Burgos' Cathedral, perhaps the greatest of the Spanish gothic architecture, and considered as a part of the Human Historical Patrimony by the UNESCO since 1.984.

A complete testing list has been carried out on quarry samples in the Laboratorio Oficial para Ensayo de Materiales de Construcción (LOEMCO), (Official Testing Laboratory on Construction Materials), which depends on the School of Mining Engeneering of Madrid and on the Spanish Ministry of Industry. The mercury's porosimetry and colour determination have been made at educational Units of Mineralogy-Petrology and Applied Physics of the School of Mines. Most of the facts come from the Career-End Project of Aurelio De Grado, written under the direction of Professor Octavio Puche. Some small facts whereof we lacked have been supplied by the Natural Stone Association of Castilla - León (PINACAL).

The laboratory work has been completed with the bibliographical analysis of the few available data, and visual analysis of some monuments and buildings, in Burgos, Covarrubias and Madrid, on which indicators and alteration mechanisms have been studied.

Finally, after correlating the country and laboratory data, some conclusions can be obtained on the behaviour of this stone under weathering conditions; these conclusions should be useful for the eventual treatment and restoration of the buildings.

Historical considerations

Hontoria's stone has been used since the earliest times of the Spanish history, for ornamental and building purposes. It seems that some "stellae" (gravestones) in the neighboring celtiberian roman town of Clunia, in Peñalba de Castro (Burgos), were made of this stony variety (Grandson, 1947). The configuration of its porous system has made possible its good conservation, even though the burials were set in wet ground and suffered a very cold climate for two thousand years.

This rock was profusely used in the Middle Age; it was the main building material of the Burgos' Cathedral, one of the best samples of the spanish gothic architecture, built between the XV and the XVI centuries. In this building were also used, though in lesser extent, Carcedo's and Bribiesca's stones. Hontoria's stone has not only been employed in the Cathedral, but in every monument in Burgos, as in the Cartuja de Miraflores (Miraflores Carthusian monastery) and the Casa del Cordón (Ribbon House), amongst many others. As well, it appears in the ashlars of the monuments of some other provincial ancient towns, for example in Covarrubias, or in some isolated monuments as the romanic monastery of Rodella. In the XIX century its use spreads out of the nearest zone, becoming very frequent its application to restorations, as a sustitution stone, for example in Leon's Cathedral. In Madrid, Hontoria's stone appears in singular modern structures, as in the reformed part of the General Headquarters of the Army or Buenavista Palace (1870), Escuela Técnica Superior de Ingenieros Navales (1941), Consejo Superior de Investigaciones Científicas (1942), Residencia de la Compañía de Jesús (around 1945), Corte Inglés General Stores, etc.

General features

The nowadays quarries of Hontoria's stone are placed on white fossi-liferous marine limestones belonging to the Santonian (Upper Cretaceous), as can be clearly inferred from the paleontological analysis. The whole is formed by a 40 m thick massive bank of limestones, in which 5 to 8 m thick strata can be distinguished, separated by thin clayey levels. Above them, in thicker banks of 10 to 15 m, the Campanian limestones can be seen as well, with a total width of 50 m. In those limestones several rests of ancient quarrying can also be found.

Regularity in composition, distance between fractures from 12 to 14 m, and strength of the rock, make economically possible the underground mining, carried out through the caving and pillars method.

The rock chemical composition is almost exclusively CO_3Ca (96 %), also some CO_3Mg (1 %), SiO_2 (1 %), Fe_2O_3 (0,5 %) and other oxides or sulfides in less extent. The very limited dolomitization of this formation in Hontoria is surprising, and different of what happens in some other places.

Visually some organic patterns can be appreciated; for example, some forms of equinidae, rudistae, gasteropods and others, whose maximum size reaches 3 or 4 mm. It can be seen through the microscope how these rests are joined by a sparitic cement, with a grain size that becomes smaller in the surrounding zones of the fossils. The walls of the external molds are recovered by microcrystaline quartz, with maximum grain sizes never higher than 0,5 mm. Sometimes, in the holes, and in small fractures, inclussions and recovering films of iron oxide can be found. Ocasionally, we have also seen other structures, mainly oolitic, grown up around quartz grains. From a petrological point of view, this rock can be considered as a "biosparite" (Folk, 1959).

This rock has been extensively employed in carving, because of its small grain size, homogeneous texture, and freezing resistance. The carved woks have been used either internal or externally, and placed in different sites, as in the pinnacles, roof's ribs in the vaults and gates in Burgos' cathedral, in the Adolfo de Pescara's burial recumbent statue and many others. The mentioned stone features were the ones that determinated its employ in the Burgalese monuments, bringing the material from a 26 km distance, despite the existence of nearer quarries of miocene limestones in Carcedo.

Moreover the carving, and although this rock is not good at all for polishing, some other finishing works, locally named as "abujardado", "apumazado", "apiconado" and others (more o less granulated sufaces), are employed for ornamental and practical uses.

Study of the material.

Apart from the quantitative analysis, petrographic studies and exami-nation of the material in quarry, some laboratory tests have been made in order to determinate its physical features.

The compression strength tests (UNE 22-184.85) have given results between 16.3 and 23.5 MPa· usual numbers, even a little high in the limestones' group, which determinates its employ in ashlar masonries and other structural uses.

The flexure strength tests have been made with test samples of 20 x 2 x 4 cm, 30 x 2 x 5,4 cm (UNE 22-186.85) and 16 x 4 x 4 cm, getting medium results between 2.61 and 4.36 MPa; the dispersion of results obtained are thought to be an index of the sensitivity of the test, having the size of the test samples a certain influence on it.

The impact strength value (UNE 22-198.85) is 0.233 m, and has been supplied by PINACAL, from previous tests made in the LOEMCO. All the given results are in the normal limestones' strength ranks.

In the same way the fastening strength of plates in frontages (NFB 10-514) gives a result of 144.9 MPa, which is quite high for a limestone. However, the great number of holes aids the close union between plates and cement mortars, and it is almost impossible to separate the slabs without breaking them.

The AFNOR hardness obtained is 5, a high number for a limestone rock.

In general terms, it can be said that the results obtained in the laboratory, together with the facts verified in the buildings, guarantee acceptable strength numbers.

The hydric characterization of the rock has been made, among other methods, through absortion-desortion tests, with apparent specific weight previously determinated (UNE 22-185.85). The obtained results, between 7 and 8 %, show a medium porosity. The final saturation water content, in ten days, is 8,72 %

The water free absortion curves by immersion show the characteristic shape for these rocks, with a high absorption speed at first and, after a transition period, a tract of asymptotic convergent curve towards the saturation number (fig.- 1). The evaporation developes in a similar way: at the beginning a high kinetic process can be seen, that dacays progressively until it reaches a number close to the rock humidity contents in dry conditions (fig.- 2).

The apparent specific weight obtained is between 2,09 and 2,24 g/cm^3.

The study of the porous system has been made with mercury porosimeter (PoreSizer 2320), supervised by Lázaro Sánchez. A bimodal porosity curve can be seen in the graphic in which the pore volume is plotted versus the pore size (fig.- 3). There are two families of pores, the

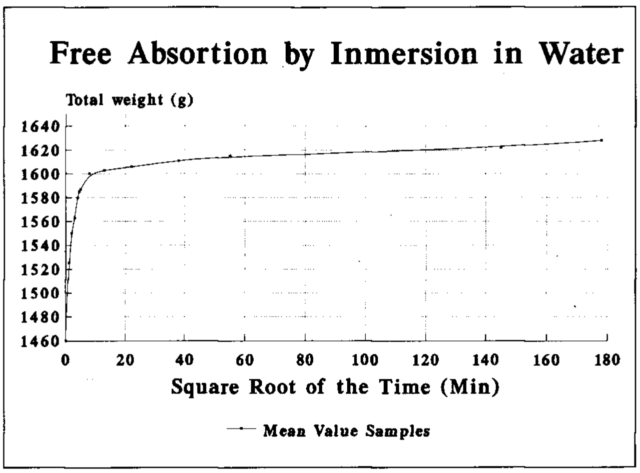

Fig. 1 - Free Absortion by Inmersion.

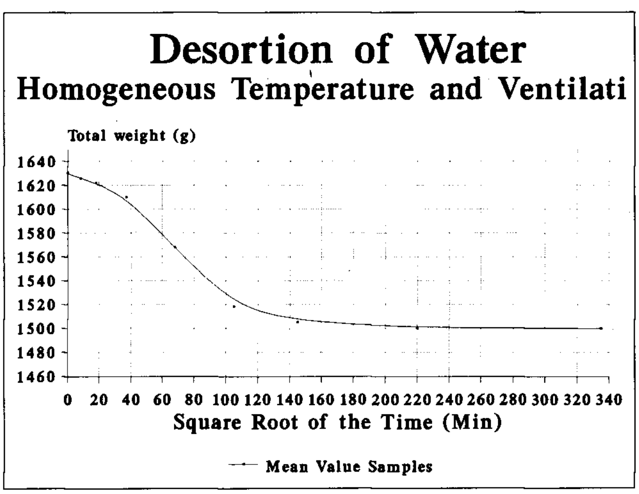

Fig. 2 - Desortion of Water.

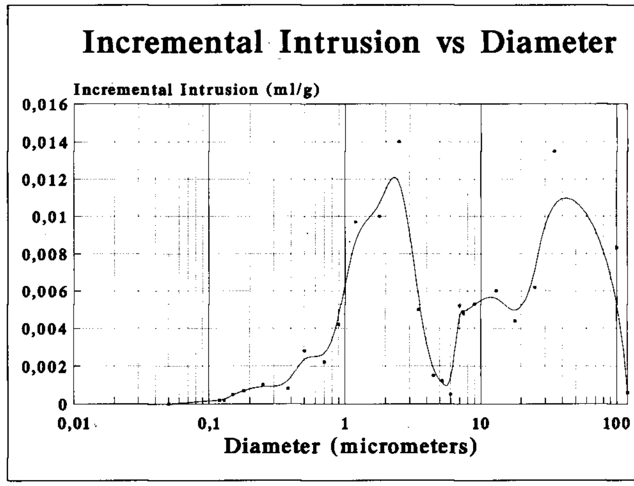

Fig. 3 - Incremental Instrusion vs diameter?

first of which is the most important with reference to volume, with diameters between 30 and 100 microns, and a maximum of 35 microns (macropores). The second family show diameters between 1,5 and 3 microns (micropores). There are also many moldic pores of organic origin, with diameters up to 4 mm.

Concerning to the weathering, and because of the cold climate of Bur-gos, some freezing tests have been made (UNE 22-184.85), and we have obtained a freezing coefficient of 0,08 %, not very high. In the same way, the quantified measure of resistance to termic changes, following the ASTM standard, is -0,16 % in weight, low for a limestone.

The attack test in SO_2 atmosphere gave a result of a loss of 0,11 % in weight in 21 days, keeping the samples at 20 degrees centigrades and 10 cm over the acid surface (the acid is a dilution of 0,15 l of H_2SO_3 at 5 % in 0,5 l of water). Little superficial alterations were observed, ocasionally with ferrous aspect.

The colour, white with the naked eye, was studied with spectrumphotometer (Color Quest C-40267), in the Educational Unit of Applied Physics of the School of Mines, in Madrid. We obtained a whiteness (following UNE standards) of 114,76, with 10 % of yelowishness and a wave length of 578 nanometers, very close to the red colour. This light reddish colour is thought to be due to the presence of iron oxide, which existence has been verified either by microscopy and quantitative chemical analysis.

Weathering damage

The climatic parameters and the pollution, together with the inherent properties of the rock, are the condi-

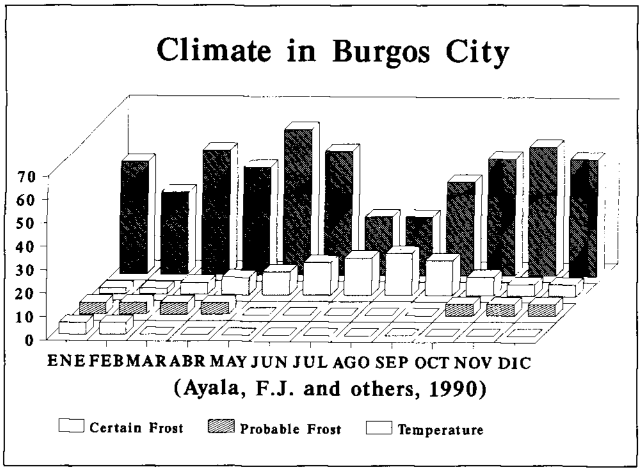

Fig. 4 - Climate in burgos City.

tions that will determine its alterability time through.

Following the Papadakis clasification, the Burgos' climate is mild mediterranean. In the same way, according to Walter and Lieth, it is in the IV subregion, mediterranean climate, moderately warm less dry: with an arid period, but also with a really cold winter (the medium temperature in the colder month is below 6 grades centigrades and with certainty of frost). Annual rains are between 500 and 650 mm (fig.- 4).

According to facts shown by Elías and Ruiz-Beltrán, in Burgos city, the annual medium of rain reaches 564 mm., below the potential evapotranspiration, which is 767 mm. This one is higher than the former from April to October.

The thermic dayly oscilations are very important, and they are higher in summer. As well, are certain the frosts in January and February, and possible, but not sure, from the beginning of March until the middle of May, and from the middle of October until the end of the year.

In the other hand, from autumn to spring, thermic inversions happen, due to the sustantial cooling of the ground night through. The cold air accumulates close to the ground, which makes difficult the diffusion of the polluting substances.

After a visual inspection, it has been verified that one of the main causes of alteration of this stone in Burgos city is the sulfation with black crusts formation and the consequent sanding under them. This, nevertheless, never happens in Covarrubias, 40 km Southward. The capital was founded in the valley of the Arlanzon river, confined between two hills, in the North and Southeast, whereas Covarrubias is in an open valley. Moreover, Burgos has a higher human concentration, and quite a high manufacturing level. However, industry is not the main source of emission of atmospheric contaminating substances, but the heating systems, which work for many hours and many days per year, due to the extremely cold climate in this part of the country. In 1961, Iñiguez had already noticed the grey colour of the stone in the pinnacles of the Cathedral, because of the dust, and the black crusts in the socles and statues in the gates of Coronería and Sarmental.

It is to be noticed that the main frontage keeps still relatively well preserved over the rose window and up to the top, which are the cleanest zones. This state can be seen in the North and West frontages. In all these zones there is a predominance of calcin (produced by a carbonic dioxide solution in cold climate) and the surface of the stone becomes harder.

The East and South frontages are in a worse state. In the former, in the vicinity of Llanas Square, a high evaporation through the surfaces (sunny and well ventilated walls) has produced many alveolar structures. In the latter, the thermic oscillations have been the cause of an important scale. The different values of the expansion coefficients of the crust and the stone causes tensions which produce the peeling of the altered zone, showing below a more or less sandy material. As well, the low thermic conductivity of the rock produces different dilatations between the external and the internal parts of the wall, which can also produce disjunctions. Even though Hontoria's stone show low values in the freezing modules, in the ashlars in contact with the ground it can be seen a severe scale caused by the persistence of the freezing in the capillar water.

In general terms, although the rock shows a medium porosity, the relatively large size of the pores is an aid to prevent the deterioration caused by salts cristalizations or freezing. In many cases, there are holes big enough to absorb the generated tensions.

Concerning the bioalteration, algae, mosses and superior plants have grown, and also a variety of lichens with a calcifilous origin. These are not considered as deterioration indicators, because it is assumed that they provide a sort of aesthetic value to the monumet.

In the same way, some other local alteration phenomena have been observed, such as cable and nail oxidations, saline efflorescences (generally indoors) etc., but they never have been important problems. Chromatically, the original intense white turns, with the long exposition to external agents, in a light grey colour range. In Covarrubias, an area with no pollution, the stone gets a golden tone.

In Madrid, this rock does not seem to suffer an important alteration. It has to be noticed that it has only been for fifty years in the buildings that have been studied, and it shows a good behaviour.

Conclusions

This rock is an important monumental variety; it has been used in Burgos' cathedral and in Leon's cathedral restorations, and it has also been used in several architectonic groups and in singular buildings.

It has quite good mechanic, hydric and weathering characteristics. Its behaviour in contact with agressive agents is good, and it works pretty well even in polluted cities, as Madrid.

Enough reserves (minimum 130 years, at actual quarrying rates) and easy mining makes the Hontoria stone interesting from the production point of view.

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