Chapter 8.3

INFLUENCE OF FABRIC ON THE PHYSICAL PROPERTIES OF LIMESTONES

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Abstract: The textural and physical properties of three Hungarian limestones; a compact, a porous and a travertine were studied in detail. Analytical methods included micro-textural analyses and laboratory testing of rock mechanical properties, such as density, water absorption, US sound velocity, UCS and indirect tensile strength. Cylindrical specimens were tested in air dry and water saturated conditions. Rock mechanical tests with combination of fabric analyses have shown that strength parameters depend not only on amount of effective porosity but also on the type of calcite cement and pore-size distribution. The porosity alone does not necessarily reflect the influence on water absorption on the properties of limestone.

Key words: limestone; travertine; microscopy; calcite cement; rock mechanics; water absorption; porosity; UCS.

1. INTRODUCTION

Limestone is one of the most common building and dimension stone. It has been used worldwide and monuments from the prehistoric times (eg. megaliths of Malta) are known to built from these carbonates. Although the primary mineralogical composition of various limestones is mostly calcite limestones show significant variations in properties and texture. From textural point of view spongy porous limestones to massive compact marble-like limestones are known[1]. The behaviour of these carbonates has been studied in many ways, especially focusing on physical properties[2] and the relationship between physical properties and different test conditions[3-4]. The present

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study deals with three texturally very different Hungarian limestones. Petrographic and physical differences of a compact limestone, a porous limestone and a travertine are characterized by using microscopic analyses and rock mechanical laboratory tests. This study demonstrates that textural differences of calcitic rocks are also manifested in physical differences, especially when water is also present. The importance of calcite cement types and pore-size distribution is also emphasised.

2. METHODS AND MATERIALS

For laboratory analyses rock blocks were obtained from active quarries. Before sample preparation the limestone blocks were described in detail and were classified according to visual macroscopic properties. Thus from the three limestones seven textural types were identified and tested under laboratory conditions. From the limestone blocks cylindrical test specimens of 5 cm in diameter were drilled by using traditional coring techniques. Thin-sections were prepared by using resin impregnation to visualise textural and mineralogical properties. Physical and rock mechanical properties were determined under laboratory conditions for air dry and water saturated test specimens. Density properties, US sound velocities, UCS and indirect tensile strength (Brasilian tests) were measured on 175 cylindrical test specimens.

The three limestones studied represent wide ranges of origin and textures. The oldest one is Jurassic compact limestone from Gerecse Mountains Central Hungary. This red, fossiliferous limestone has been used as dimension stone from the Renaissance (e.g. Medieval royal palace of Visegrád, Hungary). It displays red nodules and both in use and in appearance it is very similar to the Amonitico Rosso of Verona.

The second set of samples represents one Miocene formation, with various lithologies. The white, yellowish porous limestones often contains ooids and thus it is similar to well-known dimension stones of UK and France such as the Great Oolite or Portland Limestone (UK) or Jaumont Limestone (France)[5]. This type has been used in several monuments of Hungary such as the House of Parliament, the Opera or the Basilica in Budapest. Similar types of limestone were used for the construction of several monuments in Vienna (St- Stephan's Church, The Opera, Palace of Schönbrunn)[6].

The third limestone is a travertine, which was formed from Pleistocene springs and thus it is of freshwater origin[7]. The travertine was already used by the Romans in Budapest and aqueducts and amphitheatres were constructed from this stone. The appearance and the usage are very similar to the classical Italian travertine of Tivoli (quarries are found near Rome)[8]. Travertine has been used in several monuments such as in the footings of Parliament and at Mathias Church in Budapest[9].

3. RESULTS

3.1 Macroscopic and microscopic properties

Red compact limestone has a mottled to nodular appearance (Figure 1). According to textural and X-ray diffractometry analyses besides calcite it contains clay minerals (illite) and hematite. The clay minerals and hematite accumulates in the darker red mottles. The microbioclastic wackestone fabric contains pelagic micro-fossils and fragments of ammonites (Figure 2a). The effective porosity is less than 0.5 % and is related to clayey styolitic seams.

Textural analyses have shown that porous limestone is divided into four different fabric categories: i) coarse grained bioclastic limestone (Figure 1c), ii) medium grained oolitic limestone, iii) fine grained oolitic limestone and iv) fine grained micritic limestone (Figure 1d). The first type exhibits a bioclastic ooidal grainstone texture with large (up to cm-size) shell fragments. Its pore system consists of large mm- to cm-size intergranular and smaller intragranular pores. Pore spaces are only partly occluded by sparitic calcite cements, the effective porosity is nearly 25%.

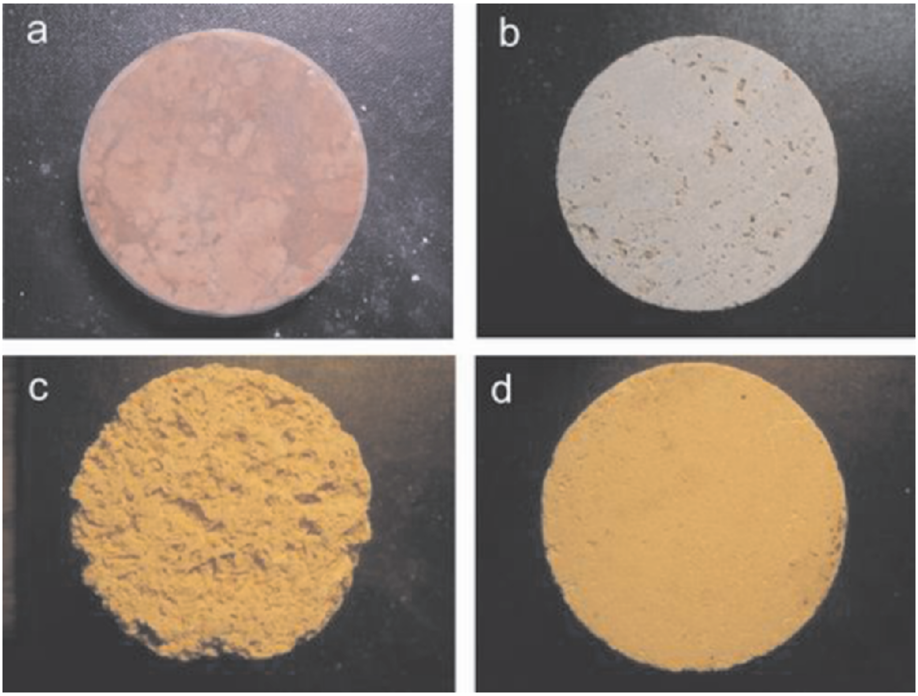

Figure 1. Macroscopic appearance of Hungarian limestones: (a) compact limestone; (b) travertine; (c) coarse grained bioclastic limestone; (d) fine grained micritic limestone.

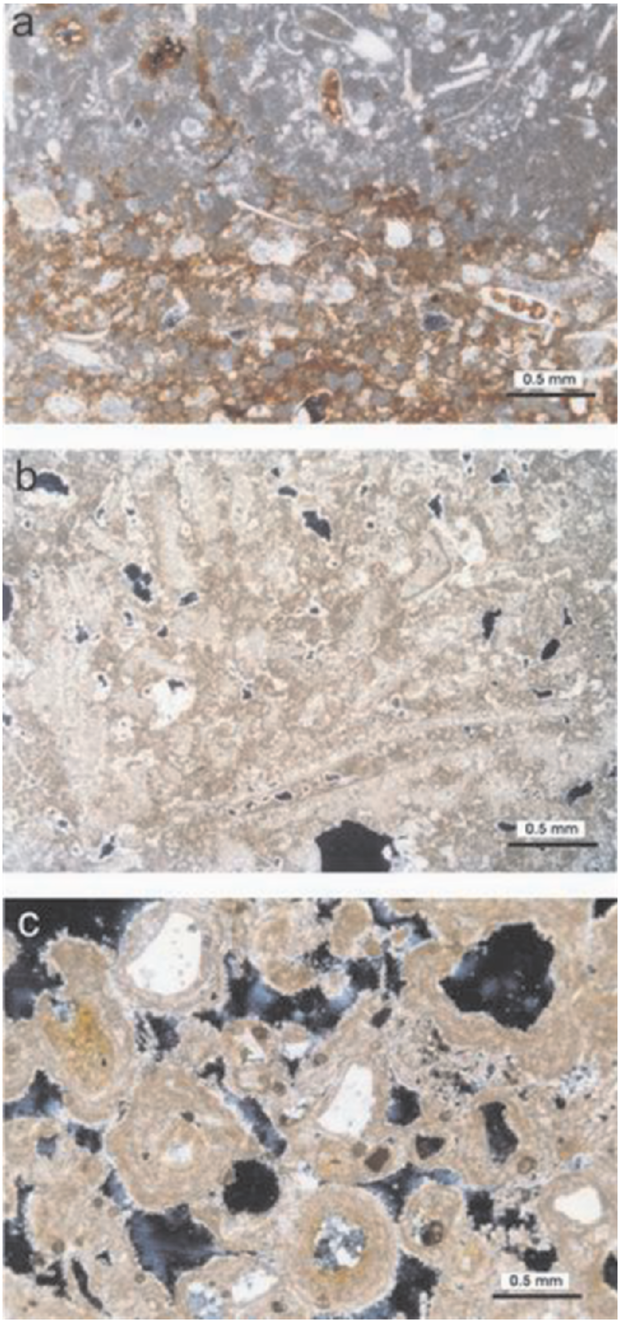

Figure 2. Microscopic image of Hungarian limestones showing various types of calcite cement and pore structures: (a) compact limestone with micritic calcite that contains small pelagic bioclasts and ferrous stylolites (lower part) showing no visible pores; (b) travertine with partly cemented pores and phytoclasts ; (c) oolitic limestone with minor cement between ooids and large irregular interconnected pores (black areas represent open pores).

Medium-grained oolitic limestone contains well rounded ooids of 0.1-0.8 mm in diameter (Figure 2c). The fabric is ooid grainstone[5]. Pores are mostly intergranular ones with an average pore size of 0.1 mm. Thin rim of sparitic calcite cement is often observed on pore walls. Its effective porosity can reach 28%.

Fine grained oolitic limestone is ooid-graintsone/packstone with smaller rounded carbonate particles ooids and peloids of 0.05-0.1 mm in size. The pores are also in the same order, but effective porosity exceeds 32%. Fine grained micritic limestone has a different fabric from the previous ones since small crystal-size calcite (i.e. micrite) is the dominant. Ooidal to bioclastic wackestones/packstones are the main fabric types, with very small matrix dependent pores providing an 8% of effective porosity.

Travertine is divided into two groups[10] based on fabric: laminated macroporous travertine and massive travertine with small pores (Figure 1b). The first laminated-type, has large (up to cm-size), irregular pores that are parallel to bedding and often contain large calcified plant fragments. In thin section it is characterised as stromatolitic phytohermal to phytoclastic boundstone. This type of travertine has an effective porosity of up to 10% which reflects the influence of a complex network of macroscopic intergranular and microscopic intragranular pores. The second travertine contains smaller but irregularly distributed pores, with effective porosity of 5%. Gastropods, smaller fragments of calcified reeds or oncoids comprise the main carbonate grains within the bioclastic wackestone to peloidal, oncoidal packstone fabric (Figure 2b).

3.2 Physical properties

Compact limestone has the highest density (2692 kg/m^3) which does not change significantly when the limestone is water saturated (2705 kg/m^3) (Table 1). The effective porosity is less than 1 % (0.5%) being the smallest from all analysed limestones (Figure 3). The maximum US velocity was measured in water saturated compact limestone with values of 5.2 km/sec. The compressive and tensile strength of compact limestone do not show significant changes when dry and water saturated samples are compared, 57.6 MPa to 41.7 MPa and 6.5 MPa to 5.6 MPa respectively (Table 1). Despite the low porosity the tensile strength of compact limestone is not the highest since according to tests massive travertine has a tensile strength of 6.9 MPa (Figure 4).

Porous limestone varieties have a wide range of density values starting from 1570 kg/m^3 and ending at 2356 kg/m^3. The trends in porosity are not necessarily similar to the densities since the highest porosity 33.1% was measured on fine oolitic limestone which has not the smallest dry density (1693 kg/m^3).

The porosities of the Miocene porous limestone are in between 8.5% and 33.1%. The smallest porosity value was recorded for samples of fine micritic limestone while the most porous type is the fine oolitic limestone with small but interconnected pores (Table 1).

Although the compressive strength of most Miocene limestones is below 10 MPa the very fine grained micritic limestone which has the smallest porosity (8.5%) shows a dry compressive strength of about 34 MPa, which drops to about 13 MPa when water saturated samples are tested. The US velocities, also, show some changes when dry and water saturated Miocene limestones are compared but this shift is opposite since air-dry US sound velocities are in the order of 1.6 to 3.5 km/sec while the water saturated ones are always greater (1.9 to 3.6 km/sec). It seems that the tensile strength of various Miocene limestones is in good correlation with porosity values (Figure 4).

The porosity of laminated travertine is nearly double than that of the massive one, 10.2 and 5.4% respectively (Figure 3). The densities are not significantly different (2251 kg/m^3 for the laminated, 2516 kg/m^3 for the massive one). The strength parameters reflect better the textural differences since the dry compressive strength of laminated travertine is 31.2 MPa, whereas strength value for massive travertine is 89.1 MPa in average. The compressive strength does not show marked change when the test results of water saturated and dry travertine is compared. Nevertheless, indirect tensile strength slightly decreases with water-saturation. The relationship between porosity and tensile strength is not so clear for travertine since massive travertine represents a minor anomaly from the general trend line (Figure 4).

Table 1. Physical properties of Hungarian limestones

Type	Porosity [V%]	Density dry [kg/m^3]	Density water sat. [kg/m^3]	Compr. strength dry [MPa]	Compr. strength wat.sat. [MPa]	Tensile strength dry [MPa]	Tensile strength wat.sat. [MPa]
Compact limestone	0.5	2692	2705	57.6	41.8	6.5	5.6
Coarse bioclastic	24.3	1570	1725	4.3	3.5	1.1	0.7
Medium-grained oolitic	28.7	1573	1802	5.3	4.4	1.0	0.4
Fine oolitic limestone	33.1	1693	1908	6.7	3.8	0.5	0.3
Fine micritic, small pores	8.5	2356	2470	33.6	13.1	2.6	1.0
Laminated travertine	10.2	2251	2341	31.2	31.9	4.7	3.0
Massive travertine	5.4	2516	2566	89.1	87.8	6.9	6.5

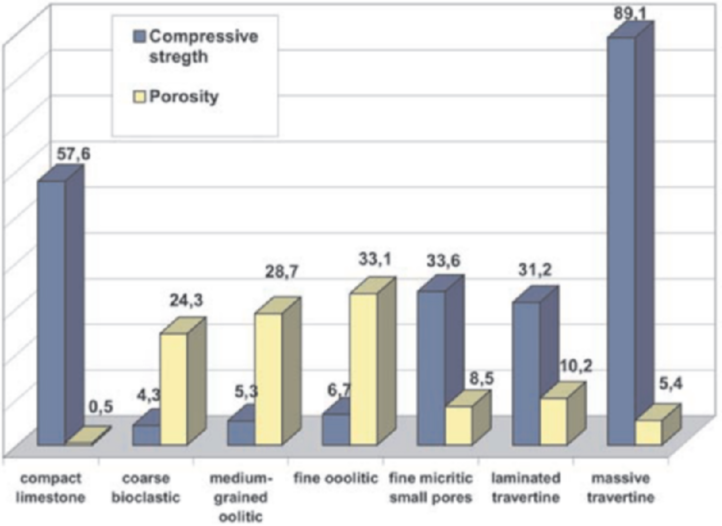

Figure 3. Compressive strength (MPa) and porosity (%) of limestones with different fabric.

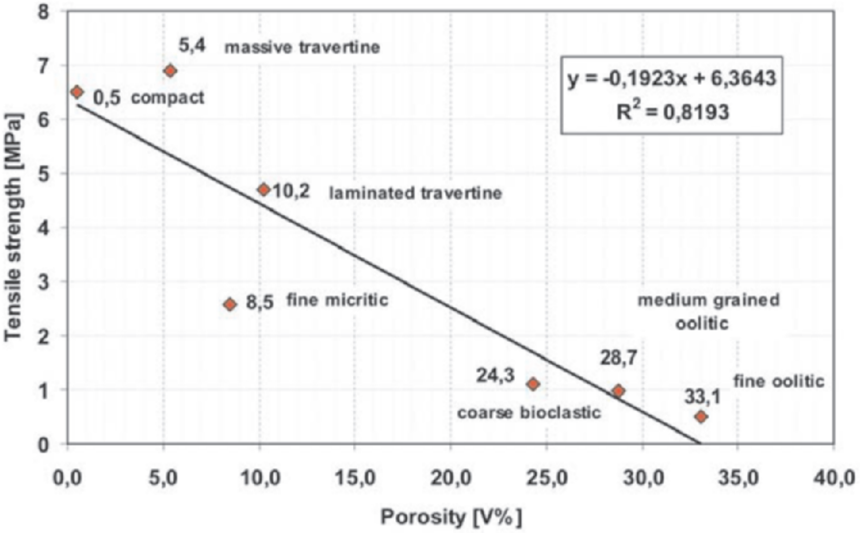

Figure 4. Correlation between tensile strength and porosity of limestones (porosity is shown in numbers).

4. DISCUSSION

The density of limestones varies between 1570 kg/m^3 (coarse bioclastic limestone) and 2692 kg/m^3 (compact limestone), but it is not in direct correlation with porosity values. The discrepancies are observed for very porous limestones. US sound velocities reflect the compressive strength values.

There is a relationship between tensile strength and porosity of limestones[11] although it seems that at some limestone types (fine micritic with small pores and laminated travertine) the correlation between porosity and tensile strength is less evident (Figure 4). This feature is related to the various calcite cementation and microscopic fabric of the limestones. The fine micritic limestone has micritic cement (1-5 µm size calcite crystals) with very small pores and thus its strength values drop below the trend line, while laminated travertine has coarser micro-sparitic cements (15-30 µm) which cause a shift of values above the trend line.

The tensile strength values of limestones with high porosity show a drastic drop when air dry and water saturated test results are compared (medium oolitic to 42%, fine micritic with pores to 37%) (Table 1). Massive travertine with higher porosity is less sensitive to water than compact limestone since its tensile strength from 6.9 MPa decreases to 6.5 MPa, while for compact limestone this change is 6.5 MPa to 5.6 MPa.

For the compressive strength the porosity and strength values are more scattered. Massive travertine with its effective porosity of 5.3 % has a uniaxial compressive strength (UCS) of 89.1 MPa while compact limestone with lower effective porosity (0.5 %) displays a smaller UCS (57.6 MPa) (Figure 3).

5. CONCLUSIONS

The porosity of limestones provides preliminary information on strength values but the correlation between porosity and tensile strength depends on the type of calcite cement, i.e. the fabric of limestone.

Densities not necessarily indicate the porosity of limestone; discrepancies are mostly observed in porous limestones.

Porous limestones when cemented by fine grained micritic calcite (µm-size crystals) are more sensitive to water than those which are cemented by micro-sparitic calcite (tens of µm).

Significant variations in strength and porosity are observed even within one type of limestone depending on the texture.

Rock mechanical tests with combination of fabric analyses have shown that strength parameters depend not only on the amount of effective porosity but also on the type of calcite cement. Consequently detailed micro-fabric analyses provide valuable information on the durability and strength of limestones.

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