Bull Eng Geol Environ (2008) 67:485–490
DOI 10.1007/s10064-008-0145-2

ORIGINAL PAPER

Physico-thermal and mechanical properties of Sanliurfa limestone, Turkey

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Received: 17 September 2007 / Accepted: 3 January 2008 / Published online: 26 March 2008

Abstract Sanliurfa limestone is becoming increasingly popular for both interior and exterior building applications in the local area in south east Turkey, being easy to cut and shape and suitable for many purposes. Although these limestones are low cost construction materials, they are not widely used elsewhere due to the lack of data regarding their chemical, physico-thermal and mechanical properties and the requirement for highly skilled labour. A total of 264 samples of Sanliurfa limestone from four quarries were tested to determine their physico-thermal and mechanical properties. The data obtained confirmed they satisfy the main international standards for the use of limestone in the construction industry.

Keywords Sanliurfa Limestone · Chemical · Physico-thermal · Mechanical properties · Turkey

Introduction

Limestones are abundant in the Sanliurfa area of southern Turkey (Fig. 1), the majority of which are reef limestones of Middle-Upper Eocene age (the Fırat Formation). In additional there are argillaceous/chalky limestones referred to as the Sanliurfa Formation (Canakci et al. 2007). The locations of the four quarries investigated are shown in Fig. 1. Figure 2 gives examples of the old and new quarries in the region.

Prior to the use of reinforced concrete structures, limestone was the main building material for major construction in the area. Today, it is still used to a limited extent as a structural material or as external cladding (Fig. 3) and interior finishings for walls. Since the South Anatolian Project (GAP) was initiated in the 1980s, there has been an increase in the popularity of limestone for use as an architectural and structural material, not least because in Sanliurfa, limestone construction is cheaper than using reinforced concrete. As a consequence, there is a need to understand better the performance of the limestone under structural loading.

Sanliurfa limestone can easily be cut with a hand-held saw (Fig. 4). Masonry wall units are produced from different sources or materials or shaped from stone extracted from different quarries. Connecting these units together with a cement or lime mortar binding material produces different kinds of masonry walls for civil engineering structures. All of the types of limestone in Sanliurfa are suitable for building masonry walls. In addition to accessibility and ease of quarrying, the limestone satisfies the requirements of strength, water absorption, unit weight, workability, porosity, durability and appearance, except for abrasion resistance.

Experience has shown that the unique characteristics of the Sanliurfa limestone are based on their architectural and structural properties—relatively good mechanical properties, easy workability, sound absorption and thermal isolation, aesthetical and historical appearance etc. However, with the increasing size of modern buildings, two

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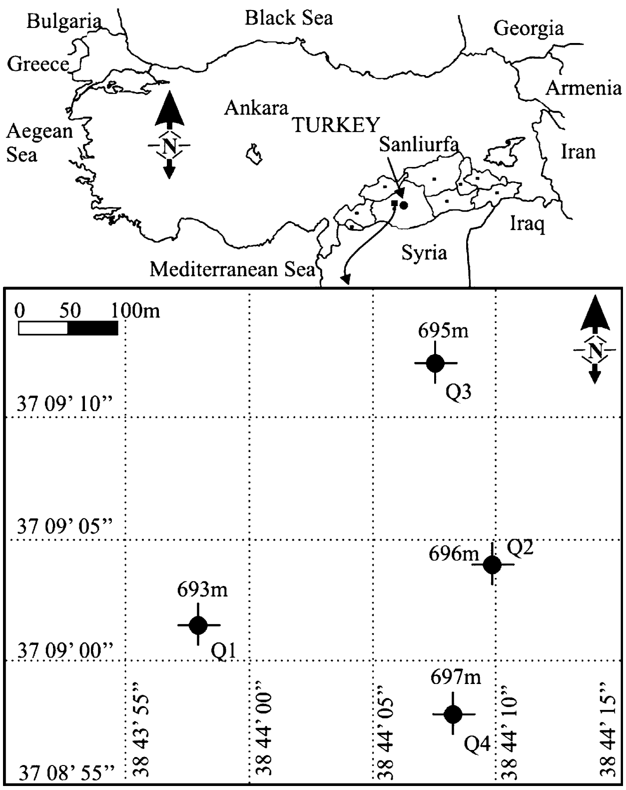

Fig. 1 Map of Turkey and the location of quarries investigated

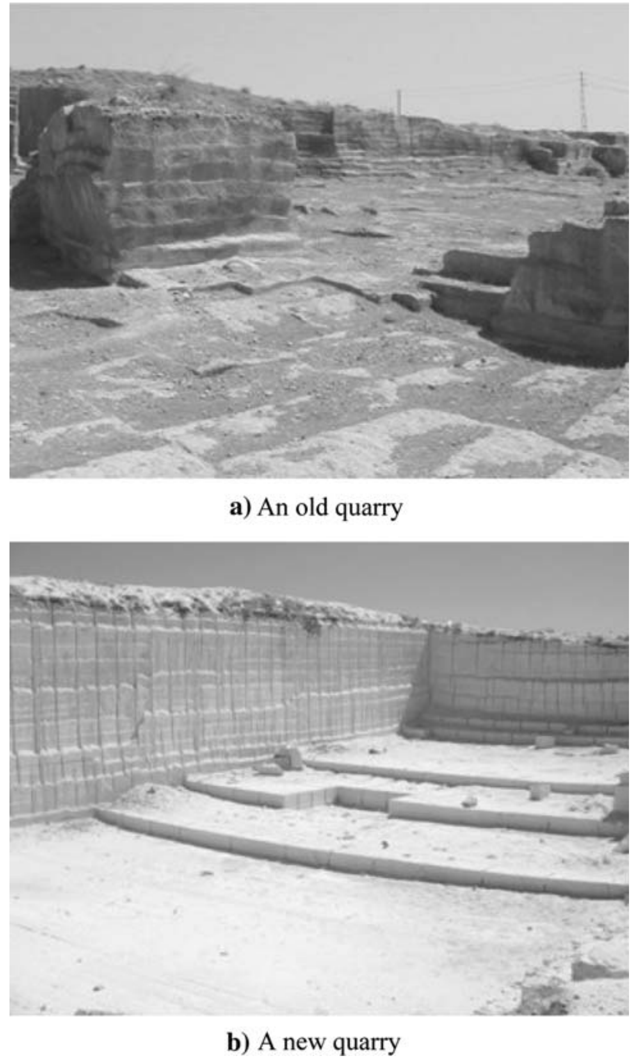

Fig. 2 Old and new quarries in Sanliurfa.**a** An old quarry. **b** A new quarry

Fig. 3 A cladding application on reinforced concrete

important questions arise. How are the material properties of the limestones affected by higher loadings and today's environmental conditions?

In order to answer these questions, samples were collected from four quarries in the Sanliurfa area (Figs. 1, 2) for laboratory testing in order to assess the qualities of the limestone in terms of international standards for use in construction.

Chemical composition

The chemical analysis of the limestone samples was undertaken using atomic absorption spectrometry. The samples are prepared by fusing the powdered material in a platinum crucible using a 12:1 ratio of lithium tetra borate in a muffle furnace at 1,000°C. The melt was allowed to cool to room temperature and then dissolved with dilute hydrochloric acid. The results are given in Table 1.

Physico-thermal testing

Large limestone blocks (0.4 × 0.4 × 0.5 m) were obtained from each of the four quarries and cut using a diamond saw. The sizes and numbers of the tested samples are given in Tables 2 and 3, which also include the international Standards followed.

Fig. 4 A cut with handheld saw

Table 1 Chemical composition of the limestones

Chemical composition (%)	Quarry names				Mean
	Q1	Q2	Q3	Q4	
SiO_2	0.45	0.39	0.55	0.62	0.50 ± 0.10
Al_2O_3	0.30	0.31	0.27	0.28	0.29 ± 0.02
Fe_2O_3	0.25	0.21	0.17	0.18	0.20 ± 0.04
CaO	55.11	54.38	54.97	54.30	54.69 ± 0.41
MgO	0.42	0.53	0.42	0.40	0.44 ± 0.06
SO_3	–	–	–	–	–
Loss on ignition	43.14	43.55	42.79	43.85	43.33 ± 0.46
Na_2O	–	–	–	–	–
K_2O	–	–	–	–	–
Cl	–	–	–	–	–
Undefined	0.33	0.63	0.83	0.37	0.54 ± 0.23
Total	99.67	99.37	99.17	99.63	99.46

The freeze–thaw tests were carried out on 70 mm cube samples to assess the weatherability of the limestone samples by determining their strength and mass loss after 25 cycles of freezing–thawing. The test was carried out following TS 699 (2000). The temperature in the freezing chamber used in this study can be adjusted between 0 and −50°C. From an initial temperature of 25°C, the temperature of the air in the freezing chamber is reduced to −20°C in 2 h. The temperature of the water in the thawing tank was 20°C. The test procedure involved:

(a) The limestone samples are submerged in the water in the thawing tank for 2 h.
(b) The samples are placed in the freezing chamber for 6 h.
(c) The samples are totally immersed in the water in the thawing tank for 2 h.

In compliance with EN13892-3 (2004), cube samples of 71 mm were used for the determination of Bohme abrasion resistance. The abrasion system involved a 750 mm steel disc rotated at 30 ± 1 cycle min^{-1} with a solid steel counterweight applying a stress of 300 ± 3 N. In the test procedure, 20 ± 0.5 g of abrasion dust (crystalline corundum AL_2O_3) is spread on the disc onto which the sample is placed. The load is applied to the sample and the disc is rotated for 22 cycles. The surface of the disc and sample are then cleaned and the procedure repeated for 20 periods (ie a total of 440 cycles) with the sample being rotated 90° prior to the commencement of each period. The volume loss following the test is given in Table 4.

A Shotherm-QTM unit (Showa Denko) quick thermal conductivity meter based on ASTM C 1113 (1999) hot wire method was used. This method has wide applications in determining thermal conductivity of refractory materials

Table 2 Sample sizes and numbers for physico-thermal tests

Tests	Sample size (mm)	Sample number	Total sample number	Related standards
Dry unit weight	70 × 70 × 70	5 × 4*	20	ASTM C 97 (2002)
Saturated unit weight				
Water absorption				
Void ratio				
Porosity				
Density	70 × 70 × 70	5 × 4*	20	ASTM C 97 (2002)
Mass loss after freeze–thaw	70 × 70 × 70	5 × 4*	20	TS 699 (2000)
Bohme abrasion	71 × 71 × 71	5 × 4*	20	EN13892-3 (2004)
Thermal conductivity	20 × 60 × 100	3 × 4*	12	ASTM C 1113 (1999)
Specific heat				
Thermal diffusivity				
Ultrasonic pulse velocity	57 × 102 × 203	–	–	ASTM C 597 (2002)
Total			92	

*4** four quarries

Table 3 Sample sizes and numbers for mechanical tests

Tests	Sample size (mm)	Sample number	Total sample number	Related standards
Dry and saturated compressive strength	70 × 70 × 70	(5 + 5) × 4*	40	ASTM C 170 (1999)
Dry and saturated compressive strength after freeze–thaw	70 × 70 × 70	(5 + 5) × 4*	40	ASTM C 170 (1999)
Dry and saturated rupture modulus	57 × 102 × 203	(5 + 5) × 4*	40	ASTM C 99 (2006)
Dry Schmidt rebound	57 × 102 × 203	(5 + 5) × 4*	40	ASTM C 805 (2002)
Saturated Schmidt rebound				
Modulus of elasticity	50 × 100	3 × 4*	12	ASTM D 3148 (2002)
Poisson's ratio				
Total			172	

*4** four quarries

Table 4 Physico-thermal properties

Tests	Quarries				Mean
	Q1	Q2	Q3	Q4	
Dry unit weight (kN m^{-3})	19.7 ± 0.2	20.6 ± 0.3	21.2 ± 0.3	21.5 ± 0.5	20.8 ± 0.8
Saturated unit weight (kN m^{-3})	22.0 ± 0.1	22.3 ± 0.3	22.7 ± 0.3	23.0 ± 0.4	22.5 ± 0.4
Density	25.7 ± 0.0	25.7 ± 0.0	25.7 ± 0.1	25.7 ± 0.0	25.7 ± 0.0
Void ratio (%)	23.3 ± 0.8	19.8 ± 1.2	17.5 ± 1.2	16.3 ± 1.9	19.2 ± 3.1
Absorption by weight (%)	12.0 ± 0.4	8.0 ± 0.6	7.0 ± 0.5	6.5 ± 0.7	8.4 ± 2.5
Porosity (%)	23.5 ± 0.6	16.5 ± 0.9	14.9 ± 0.9	14.0 ± 1.3	17.2 ± 4.3
Mass loss after freeze–thaw (%)	0.06 ± 0.05	0.07 ± 0.06	0.08 ± 0.02	0.07 ± 0.02	0.07 ± 0.01
Thermal conductivity (W m^{-1} K^{-1})	1.43 ± 0.12	1.38 ± 0.18	1.54 ± 0.13	1.33 ± 0.13	1.42 ± 0.09
Specific heat (J kg^{-1} C^{-1})	904	1,066	1,119	1,076	1,041 ± 94
Thermal diffusity [(m^2 s^{-1}) × 10^{-7}]	8.03	6.29	6.49	5.75	6.64 ± 0.98
Dry ultrasonic pulse velocity (km s^{-1})	3.16 ± 0.08	3.39 ± 0.19	3.53 ± 0.19	3.53 ± 0.18	3.27 ± 0.24
Bohme abrasion value (cm^3 per 50 cm^2)	27.2 ± 0.4	27.1 ± 1.3	27.7 ± 2.3	29.0 ± 1.6	27.8 ± 0.87

(Daire and Downs 1980; Willshee 1980; Sengupta et al. 1992). The measurement range is between 0.02 and 10 Wm^{-1} K^{-1} with an accuracy of ±5% of the reading value per reference plate. Measurement temperature is from −100 to 1,000°C. Three 20 × 60 × 100 mm samples per mix are used to test thermal conductivity; the measuring time was the standard 100–120 s.

Ultrasonic pulse velocity measurements were undertaken on 102 × 57 × 203 mm rupture modulus samples using Pundit Plus (TIKO) equipment and following ASTM C 597 (2002). The ultrasonic pulse velocity through a material is a function of the elastic modulus and density of the material and is determined by placing a pulse transmitter on one face of the sample and a receiver on the opposite face. A timing device measures the transit time of the ultrasonic pulse through the limestone sample. The ultrasonic pulse velocity of the limestone samples was calculated from the path length (203 mm) divided by the transit time.

Mechanical tests

The sizes and numbers of limestone samples tested for the mechanical properties are given in Table 2. A strain-controlled loading frame having a capacity of 800 kN was used for the load applications. The uniaxial compressive and flexural strength tests were performed on dry and water saturated limestone samples. After freezing and thawing cycles, the uniaxial compressive strength of the samples was determined on dry and water saturated limestone samples. The compressive strength tests were carried out on 70 × 70 × 70 mm^3 sized cubes by loading normal to the bedding planes (as would be used in buildings) following ASTM C 170 (1999).

The dry and water saturated rupture modulus measurements were carried out on 102 × 57 × 203 mm limestone samples by loading normal to the bedding planes, following the procedures given in ASTM C 99 (2006).

Rebound (Schmidt) hammer measurements were undertaken to obtain approximate dry and saturated compressive strengths. The tests used a W-M-250 type test hammer, impacting normal to the bedding planes in the 102 × 57 × 203 mm limestone samples and following ASTM C 805 (2002).

To establish the modulus of elasticity and Poisson ratio tests, 2:1 samples were used following ASTM D 3148 (2002). The 50 mm diameter cylindrical samples were cored from limestone blocks and the end faces ground using an end-face grinder and checked for evenness and perpendicularity with respect to the vertical axis. At the mid-height of each sample, two small strain gauges were attached: one along the length (vertical) and one along the circumference (horizontal). The strain gauges were the GFLA-6-50 type (Tokyo Sokki Kenkyujo, Japan). The results given are the average of three tests.

Results and discussions

Chemical properties

As seen from Table 1, the CaO content varied between 54.30 and 55.11%; mean 54.69%. The loss of ignition ratios varied between 42.79 and 43.85%.

Physico-thermal properties

The average values of results obtained from the physico-thermal tests are given in Table 4. As can be seen from the table, all the limestone samples were found to have a high porosity, high void ratio and high water absorption, hence low unit weight.

The mass loss after freezing and thawing was low due to the high porosity, but satisfies the requirement in ASTM C 568 (2003). The mean ultrasonic pulse velocity of limestone is 3.27 km s^{-1}.

The thermal conductivity (k), specific heat (c) and thermal diffusivity (α) of a material are the three most important thermo-physical properties as regards heat transfer. The specific heat (c), is defined as the energy required to raise the temperature of a unit mass of a substance by one degree. In this study, the classical adiabatic-calorimetric method was used in measuring the specific heat of materials.

Thermal diffusivity (α) measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy, ie the ratio of the thermal conductivity (k) to the heat capacity (ρc), and is measured in $m^2\ s^{-1}$.

$$\alpha = \frac{k}{\rho c}$$

where k is thermal conductivity (W m^{-1} K^{-1}), ρ is density (kg m^{-3}) and c is specific heat (J kg^{-1} K^{-1}). Materials with a large α will respond quickly to changes in their thermal environment, while materials of small α will respond more sluggishly and take longer to reach a new equilibrium condition.

As seen from Table 4, the thermal conductivity of the limestone ranged from 1.33 to 1.54 W m^{-1} K^{-1}. The specific heat varied from 904 to 1,119 J kg^{-1} K^{-1} depending on the quarry and the thermal diffusivities (α) from 5.75 to 8.03 × 10^{-7} m^2 s^{-1}. The thermal properties found in this study for the Sanliurfa limestone are slightly greater than the values given for limestone in the literature (Ozisik 1984; Kreider et al. 2001) and better than those for some natural stones, such as granite, marble and sandstone.

The mean volume loss on wear (Bohme abrasion value) was 27.8 cm^3 per 50 cm^2. This value is 2.78 times higher than threshold limit of 10 cm^3 per 50 cm^2 given in ASTM C 568 (2003). Sanliurfa limestone is soft and can be cut

Table 5 Mechanical properties

Tests	Quarries				Mean
	Q1	Q2	Q3	Q4	
Dry compressive strength (MPa)	17.4 ± 1.8	19.6 ± 2.7	18.4 ± 1.5	15.6 ± 2.2	17.8 ± 1.7
Saturated compressive strength (MPa)	12.9 ± 1.1	16.8 ± 1.5	16.3 ± 1.5	12.6 ± 2.2	14.7 ± 2.2
Dry compressive strength after freeze–thaw (MPa)	16.1 ± 1.8	16.3 ± 3.9	17.7 ± 1.5	14.9 ± 0.7	16.3 ± 1.2
Saturated compressive strength after freeze–thaw (MPa)	11.8 ± 1.0	13.9 ± 2.5	13.7 ± 1.9	11.5 ± 0.6	12.7 ± 1.3
Dry rupture modulus (MPa)	4.35 ± 0.40	4.13 ± 0.67	5.21 ± 0.22	5.90 ± 0.25	4.90 ± 0.81
Saturated rupture modulus (MPa)	3.84 ± 0.15	4.00 ± 0.56	4.41 ± 0.42	4.39 ± 0.39	4.16 ± 0.28
Dry Schmidt rebound (MPa)	19 ± 1	20 ± 3	23 ± 1	22 ± 2	21 ± 2
Saturated Schmidt rebound (MPa)	13 ± 1	15 ± 3	18 ± 1	17 ± 2	16 ± 2
Modulus of elasticity (GPa)	15.7 ± 2.2	10.2 ± 2.1	14.2 ± 4.6	15.8 ± 3.4	13.9 ± 2.6
Poisson's ratio	0.33 ± 0.03	0.32 ± 0.04	0.27 ± 0.01	0.31 ± 0.02	0.31 ± 0.03

with a hand-held saw when it is first extracted from the quarry and in a moist condition. However, the surface hardens over time when in contact with the atmosphere.

Mechanical properties

The average values of the results obtained from the mechanical tests are given in Table 5. The dry compressive strength values of the limestones varied between 15.6 and 19.6 MPa and was 21% higher than that of the water saturated samples. After 25 cycles of freeze–thaw, the value decreased by some 8% to 16.3 MPa, indicating the Sanliurfa limestone is durable as regards freezing–thawing.

The dry rupture modulus values of the limestones varied between 4.13 and 5.90 MPa (mean 4.90 MPa) and was some 18% higher than that of the water saturated samples.

The Schmidt rebound hammer values for the dry limestone samples varied between 19 and 23 MPa, the mean being some 8% higher than the mean dry compressive strength. Not surprisingly, the Schmidt rebound number for the water saturated limestone samples was some 24% lower than for the dry. The results indicate the dry compressive strength of Sanliufura limestones can be determined approximately using the Schmidt rebound device.

The dry modulus of elasticity values varied between 10.2 and 15.80 GPa (mean 13.9 GPa). The Poisson ratio values ranged from 0.27 to 0.33 with a mean of 0.31.

Conclusions

The physico-thermal and mechanical properties of Sanliurfa limestone in general are found to satisfy the threshold acceptance values specified by ASTM C 568 (2003) for the use of limestone as a natural building stone, with the exception of the Bohme abrasion values.

Sanliurfa limestone is classified as low density according to ASTM C 568 (2003).

It is "soft" and can be cut and shaped with a hand-held saw in its moist state when it is extracted from the quarry, but its surface hardens on contact with the atmosphere.

Whilst Sanliurfa limestone has been used locally for many years as a building material, the data presented in this study confirm its acceptability according to international standards and indicate its potential for use in masonry.

Acknowledgments The authors greatly appreciate The Turkish Scientific and Technical Research Institute for the fund provided for the present investigation (under grant TUBITAK-MAG-104I084). The authors also would like to thank Miss Tanay Atasoy for her helpful comments.

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