ENVIRONMENTAL INFLUENCES ON SANDSTONE BUILDINGS IN BELGRADE (SERBIA)

V. MATOVIC[1], N. VASKOVIC[1] and N. MATOVIC[2]

[1]*Faculty of Mining and Geology, Djusina 7, 11000 Belgrade, Yugoslavia; vesnamat@beotel.yu or nadavask@eunet.yu*
[2]*Institute of Highway, Kumodraska 257, 11000 Belgrade, Yugoslavia;*

Abstract: The arkose and litarenite sandstone were used extensively as building stones. Durability of sandstones depends of theirs chemical composition as well as environmental affects. The most important damage types on sandstone blocks are exfoliation, granular disintegration, and peeling. Efflorescence and black crust occur, too.

Key words: weathering, sandstone, durability, and air pollutions.

Introduction

In Belgrade, various sandstone types of the Cretaceous and Miocene age have been used as buildings and ornamental stones. On the beginning of the twentieth century these rocks were used in different ways, as irregular slabs/blocks, or as regular layers. Later, sandstones were mainly used as stone panel in facades of objects or for parts of them (the plinths, portals, capitals etc.). Today, the most of sandstone buildings are deep weathered.

Generally, resistance to weathering of sandstones is determined by their chemical composition and physical properties but the rate of weathering is related to the vicinity of two rivers (Sava and Danube), climatic conditions and high concentration of air pollution emitted from industrial plants, heavy traffic and municipal heating and home furnaces. In addition the severity of the conditions to which sandstone is exposed depends upon its location within the building.

In the last twenty years acceleration of sandstone decay in buildings was noted. The aim of this review is to present the response of sandstone to pollution urban atmosphere.

Petrographical and physical properties of sandstones

Sandstones used for the most buildings originated from two localities. The Lower Miocene sandstones are exposed in Krusevac area (180km south of Belgrade) and the Upper Cretaceous sandstones from the Ljig (100 km SW of Belgrade).

The arkose sandstones of the Lower Miocene age are represent shallow lacustrine sediments. Sandstones are gray to yellow-brown, sometimes pink or red colored. They are massive to well bedded, often with cavities (approximately 0.5 mm in diameter) and coarse- to fine-grained (grain size vary from 0.2 to 1mm). Sandstones are composed of partly rounded to angular slightly sorted clasts of quartz, K-feldspar, plagioclase, muscovite and fragments of rocks, mainly metamorphic. Contact-pore filling of yellow and red varieties of sandstones is ferrous-calcitic cement, while in gray varieties (subordinated) is siliceous-clay.

The obtained data of physical properties, for bulk density (1880-2420 kg/m^3) and density (1940-2720 kg/m^3), absolute porosity (7.4-27.9 %) and water absorption (2.43-9.16 %) considered sandstones of Bele Vode as medium heavy, high porous rocks with moderate to high water absorption.

The Upper Cretaceous sandstones are litarenite brown to gray in color, with very different textures, from relatively fine and uniformly grained to slightly sorted fine- to coarse grained. They composed of rounded to angular grains of quartz, rock fragments (quartzite, shist and igneous rocks), feldspar and micas. The contact and pore filling cement is carbonaceous to clay-siliceous and slightly ferruginous.

Physical properties emphasized that these sandstones are. medium heavy (2460 kg/m^3), medium to high porous (9.85 %) with slightly to moderate water absorption (2.25 %).

Environmental conditions

The velocity of sandstone decay is influenced by climate and atmospheric pollution: composition of the atmosphere and rainwater, direction and velocity of wind, pollutant concentrations of air etc.

Generally, all buildings in Belgrade are exposed to the medium continental climate with wet and hot summers and a long cold winters, often with fogs and snow, and short autumns and springs. Average yearly precipitation, number of the frost-icy days and the value of high relative humidity during winter, accelerate the degradation of sandstones.

Simultaneity of precipitations (yearly average of 684.5 mm), and temperatures below 0^oC (61.5 frost days per year and 17.6 ice days per year), causes frost-defrost phenomena in the materials. Although the yearly average temperature is mild (11.9^oC), yearly and monthly thermo oscillations are considerable. During the wintertime predominant winds are from NE (maximum velocity is about 50-100 km/h). During the summer time, the highest temperatures are accompanied by the most important insulation rates.

Geographical position of town, relief, climate and rapid development of industry after 1950 caused the high concentration of air pollution. Dust and gas emission from different industrial plants as well as combustion of solid fuels and domestic emissions (smoke and soot) and traffic pollutants from motor vehicles are the main reasons of deterioration of environment quality.

Yearly average concentration of smoke and SO_2 are relatively low but for individual months (November February) daily maximum values over the sanitary limit (50 $\mu m/m^3$ for smoke and 150 $\mu m/m^3$ for SO_2) are noticed in Belgrade (Table 1).

Yearly average concentration values of NO_2 in the period from 1995 to 1998 are constantly low (between 39.6 and 51.4 $\mu m/m^3$) i.e. under sanitary limit (60$\mu m/m^3$) for Belgrade.

Differences in concentration of air pollution (SO_2, smoke) between summer- and wintertime indicate a great input of pollution related to heating system. Combustion of fossil flues releases sulfur as SO_2 into atmosphere.

Continues measurement of heavy metals show that values of Pb, Zn, Mn and Cr are under the limit, except for Ni, which is always over the limit. The highest over limit values of Pb for month is noted in the downtown and for Ni in the north periphery of town (industrial zone). From 1993 to 1999 a decreasing path of heavy metal concentration are observed.

Table. 1. Concentration of SO_2 and smoke in Belgrade ($\mu m/m^3$)

Year	1991	1992	1993	1995	1996	1997	1998
SO_2							
Average yearly	132	44.2	17.1	16.4	21.4	27.8	23.7
Winter	145.8	57.8	27.0	21.4	32.9	38.7	36.8
Summer	117.1	309	8.9	10.7	10.3	16.9	11.6
Daily max. Per month	541 September	297 January	110 December	75 February	154 November	137 February	223 December
SMOKE							
Average yearly	86.1	64.5	57.4	58.9	56.3	83.2	78.8
Winter	107.5	81.0	75.6	71.1	67.2	96.2	97.2
Summer	64.4	48.4	42.5	44.1	45.8	70.1	62.1
Daily max. Per month	704 January	372 January	376 January	357 February	285 December	326 December	440 December

The data of the Municipal Institute for Health Protection

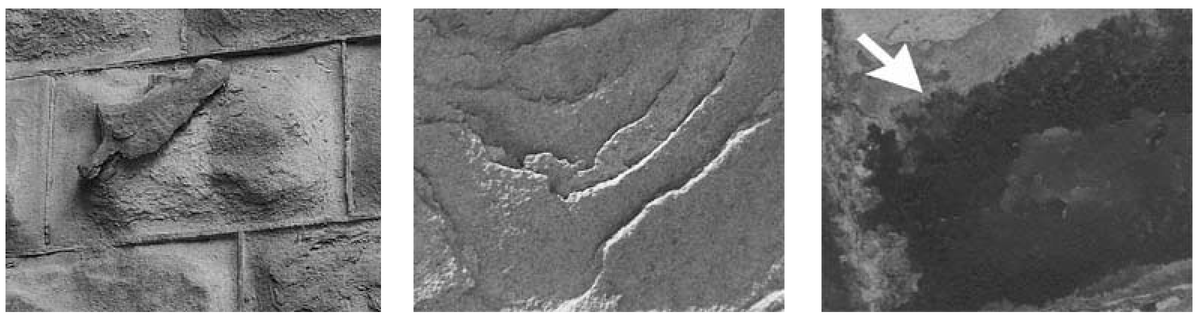
Types of sandstone decay

On sandstone elements from some buildings, deep destruction was established. The stone blocks, depending from type of sandstones, kind of superficial working, location, and distance from the river, microclimate factors atmospheric pollution, show different type of degradation: exfoliation, case hardening, granular disintegration, contour scaling, spalling and peeling. Besides efflorescence, black crust occurs, too (Matovic et al, 1999, 2000).

Deep erosion and granular disintegration always occupied all sandstone blocks in the lower part of the facades. Blowing wind, influence of rain, ground water etc. caused physical and chemical decomposition, while some elements, lost superficial shapes, with rare preserved primary parts (Fig. 1A). Peeling is developed on sheltered surface sandstones as superficial loosening of 0.5-3 mm thick sheets, tending to blister and fall off. New opened surface underwent chipping and granular disintegration. The dominant form of decay on mainly of facades is exfoliation. The primary surface of most elements was completely destroyed and sheets are separated from the stone element perpendicular to layering (Fig. 1B).

Black crust occurs on sheltered sandstone blocks, unattainable for rain. Dust particles, smoke and other atmospheric pollution are easy deposited on blocks with rock-faced quoin surface (Fig 1C).

During dry months, efflorescence of halite, thenardite, thermonatrite and gypsum occur in the upper zone of ground moisture rising. It accelerated peeling, chipping and later exfoliation of sandstone blocks.



A B C

Fig. 1. Types of sandstone decay: A – granular disintegration; B – exfoliation; C – black crust

Conclusion

The sandstones, used as stone panel for many building facades in Belgrade, are strongly disintegrated in majority of objects. Type and rate of the sandstone decay depend on mineral composition, physical properties, atmospheric influence, air pollution, position of stone elements in objects (exposed to sun and wind), as well as on the way of superficial working.

The used sandstones are medium to coarse-grained arkoses and litarenite with contact and pore filling cement (carbonaceous, ferruginous or clay-siliceous). According to porosity and water absorption, i.e. the most important properties for durability, they are high porous, able to absorb and keep water.

The form and intensity of decay imply chemical-physical influence of water and frost as the main agents. The majority sandstone elements have been deeply destroyed by exfoliation, case hardening, spalling followed by granular disintegration. The main cause of these decay types is physical activity of water and frost, which enables further chemical dissolution. As sandstones are high porous rocks, during winter (frosty and icy days), water absorbed to a certain depth enables freezing and thawing of the outer parts of elements. Repeated cycles, even daily, formed weak surface zones. At the beginning it is hardened crust that soon loses contact with the sound parts of rock, thus it's blistering and breaking, perpendicular to layering, caused exfoliation and spalling. Especially granular disintegration are evident in the lower part of facades, i.e. in the elements permanently exposed to moisture (ground water), as well as in the elements where rain and snow could be longer kept (cordon cornices, rosettes, window frame).

Sandstone blocks sheltered from the rain influence are covered with black crust due to deposition of smoke and dust from traffic, common in an urban area. Efflorescence is developed during dry periods on surfaces that are sheltered from the rain, i.e. inside or over the zone of capillary rise, where following salt could be deposited: halite, thenardite/mirabilite. Majority of sodium is originated from soil, but some parts could be from streets salted during winter, whereas sulfate (SO_4) comes from atmosphere. Over the zone of capillary rise, the main salt is gypsum and calcium for it is from mortar or sandstone.

The deterioration of sandstone is a serious problem in urban areas and the mentioned processes of sandstone decay cannot be interrupted or stopped, but it is necessary to slow down them by properly sanation and preservation.

References

Matovic V., 1999. Decomposition of stone in the riverbank pillars of Branko's Bridge. Heritage, Institute for the Protection of Cultural Monuments of Belgrade, II, 107-114.

Matovic V., Milovanovic D., Joksimovic S., 2000: Durability of sandstones in Serbian ancient monasteries and modern buildings. 9th International congress on deterioration and conservation of stone, Proceedings, vol 1, 135-144.