Stone Cultural Heritage Elements

Subjects: Others
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Stones are ones of the most ancient natural materials exploited by humans, with different uses, from tools to buildings, that have endured over time in better conditions than other objects belonging to cultural heritage. Given the importance of those silent witnesses of the past, as well as our duty to preserve all parts of cultural heritage for future generations, much effort was put into the development of materials for their consolidation, protection, self-cleaning, or restoration.

Keywords: stone heritage ; weathering ; natural factors ; anthropic action

1. Introduction

Stones are one of the most ancient natural materials exploited by humans, with different uses, from tools to buildings, that have endured over time in better conditions than other objects belonging to cultural heritage. Even though they are materials with a good durability, some external factors can deteriorate it, and keeping ancient proof of civilization for future generations can pass in a “mist of time”. Natural stones are not only a material resource, they are also cultural. They allow researchers to understand different populations’ way of life, beliefs, and values [1].

Over time, different types of stone were used to manufacture small objects, which served as tools, vessels, jewelries, or weapons [2][3][4] or for big construction projects, such as roads or buildings, defining the architectural identity of the zone [5][6][7]. The characteristics of the materials used thousands of years ago reveal to researchers in the present the dynamic of the populations, transport methods, and way of living of the ancestors [8]. In addition, using modern characterization methods, some approaches for conservation and restoration can be considered, due to their intrinsic features. Their mineralogical properties or microstructural characteristics can affect physical and mechanical behaviors [9]. The relationship with microbial colonization and development of biodeterioration and damage is also related to stone characteristics [10].

Surviving stone monuments for the future is researchers duty, so by addressing different conservation and restoration methods, researchers can slow down the deterioration process. If, in the past, stone has always been considered the most affordable and durable material, nowadays ancient stone objects belonging to cultural heritage, due to the carried cultural load, are in need for modern conservation and protection materials and technologies.

2. Deterioration of Natural Stones

When speaking of stone heritage, two main classes can be distinguished: natural stones (that can be further classified into inclusive rocks—i.e., granite, diorite, gabbro, etc., extrusive rocks—i.e., basalt, andesite, rhyolite, etc., sedimentary rocks—i.e., sandstone, limestone, gypsum, etc., and metamorphic rocks–marble) and man-made materials (such as fired or unfired bricks). A thorough classification of the stone materials (including their composition, characteristics, and uses) was previously presented by researchers group [11].

Although having the appearance of durable materials (and often resisting for hundreds or thousands of years), the cultural heritage stones are exposed to degradation, either from natural or anthropic factors. Researchers will briefly discuss some of the factors involved in the weathering of stone materials, underlining the necessity for developing tailored materials for their conservation. It must be stated that all types of weathering are in a strong connection, acting in a synergistic manner (**Figure 1**).

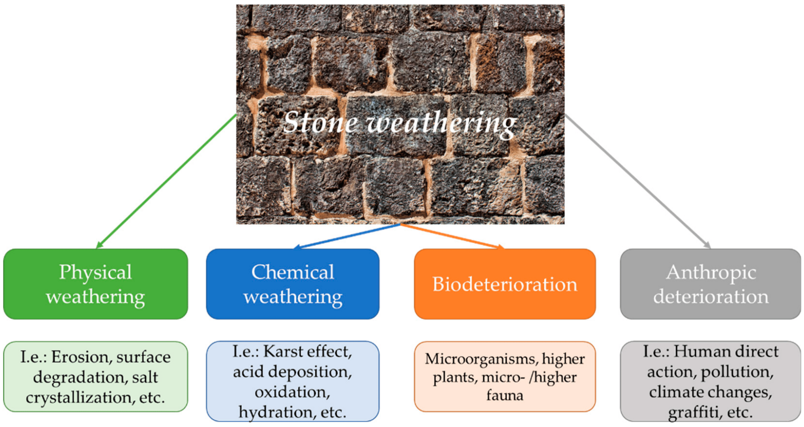

Figure 1. Types of stone weathering.

2.1. Physical Weathering

The phenomenon of physical weathering is common for most types of stone materials, being caused by natural agents (especially water, but also wind or temperature variations) [12]. One of the major types of physical weathering is the superficial erosion, determined by a combination of factors, such as rainfall, winds, and presence of particles that can act as abrasive agents. The presence of water can also lead to surface degradation of stones through expansion/contraction or freeze/thaw cycles, generating cracks, scaling, exfoliation, spalling, delamination, or contour scaling [13][14][15][16].

Most commonly, these processes are associated with porous stones (especially sedimentary rocks, such as limestone or sandstone, and man-made materials) [17] and to a lesser extent with the stones having superior mechanical properties (i.e., granites) [12].

Salt crystallization represents another common process responsible for physical weathering. Salt solutions (originating from the structure of the stone, plasters, soil–ions migrating using the capillarity of the stones, anthropogenic activities, such as agricultural practices, deicing solutions or even materials used for conservation of the artifacts, atmospheric pollution, metabolic products of microorganisms, etc.) can increase in concentration and finally crystalize with the reduction of relative humidity. With the increase in relative humidity, the crystals are rehydrated, and thus repeated crystallization/re-hydration cycles occur, which can lead to an increased mechanical stress on the stone, thus causing its weathering [18].

Recent works [16] revealed that most of the physical weathering phenomena recorded are in a strong connection with the presence of swelling clays, zeolites or micropores in the composition of the stones.

Another type of physical weathering is represented by the action of plant roots, which can be developed in the existent cracks and exert further damage [19].

2.2. Chemical Weathering

The chemical weathering of stone artefacts represents the alteration of the stone composition caused by chemical reactions. One of the most common chemical weathering, particularly affecting the calcareous stones is represented by the karst effect [12][20]. The karst effect represents, basically, the chemical transformation of calcium carbonate to the highly soluble calcium bicarbonate. The effect is aggravated by the presence of pollution related CO_2 and can lead to an increase of stone's pH, by the formation of carbonic acid and subsequent processes, which are necessary for the re-establishment of the equilibrium [12].

The acid deposition, either wet (trough acid rain) or dry (through the deposition of pollutants, such as SO_2 or NO_2) leads to the formation of acidic species and their reaction with the stone's components, subsequently forming soluble compounds, which are easily removed from the surface of the stone. As a new layer is exposed, the process is once again initiated and the stone is irremediably damaged. The process is often present in calcareous stones in which it leads to the formation of gypsum ($CaSO_4 \times 2H_2O$). Although not as sensitive as the porous stones, the highly crystalline ones (such as granite or marble) are also affected by this process. In these cases, it leads to the apparition of efflorescence, but also of a porous layer, which enables the apparition of otherwise specific to porous stones physical degradation phenomena [13][20].

The oxidation phenomenon (mostly encountered as the oxidation of Fe^{2+} to Fe^{3+}) can affect a very wide range of materials, practically any type of stone, with a minor content in any oxidation-prone metal, being exposed to the formation of oxidation stains (brittle, affecting the mechanical properties of the stone) in the presence of oxygen and water, including granite [21], marble [22], or limestone [23].

The hydration of particular minerals present in the stone structure does not represent in itself a major treat to the object's integrity, but it represents an initial step in the hydrolysis process [16]. Common examples of the hydration process are the hydration of the iron oxides to hydroxides or of anhydrite to gypsum [24].

2.3. Biodeterioration

Although, from a microbiological point of view, stones represent a very poor growth media, the biodeterioration, or degradation of stone materials induced by (micro)organisms, is encountered on all types of substrates and in all climates, the exact type of colonizing species being influenced by the bioreceptivity of the stone (predisposition of a particular material to be colonized by a living organism) [25]. Bioreceptivity is a particular characteristic of each cultural heritage site, as it is dependent on the stone structure, petrophysical characteristics, chemical composition, pH, conservation state, weather conditions, or air pollution [25].

Regarding the colonizing organisms, there are several classifications currently used: following a nutritional classification, the organisms inducing biodeterioration can be divided into photoautotrophs, chemoautotrophs, heterotrophs and chemoorganotrophs [25][26]. From a taxonomic perspective, the biodeteriogens can be divided into bacteria, archaea, cyanobacteria, algae, fungi, and lichens [11][26]. The biodeteriogens can also be divided into microorganisms, higher plants, and micro- and higher fauna [11].

The microorganisms-induced biodeterioration is manifested in a very wide variety of effects, including dissolution/recrystallization, biofilm development, chemical alterations, discolorations, etc., while the deterioration induced by higher organisms is usually associated with physical effects, such as erosion or apparition/deepening of cavities [11]. The biodeterioration represents by itself a subject of intense research, the causes, specific species affecting different types of stones, effect and treatment methods being discussed in a large number of review papers [25][26][27][28][29][30][31].

2.4. Deterioration Induced by other Anthropic Factors

As previously presented, the anthropic factors can be involved in all the deteriorations processes. Other human actions can also contribute to the degradation of stone artefacts. For example, the moisture originating from ineffective systematization, clogged drains or installation system failure can affect the stone materials to a great extent [32]. The contribution of human activities to the pollution and involvement of the pollutants in the chemical and physical degradation processes represents another important degradation factor [12], as are the activities involving the enrichment of soil found in contact with the stone artefacts in nitrates or chlorides [18], or incorrect/unsupervised conservation and restoration treatments attempts.

Climate changes can also affect the stones, not only by accelerating certain degradation processes, but also by rendering ineffective previously applied conservation materials [33]. Extreme events (such as fire) can induce a rapid and acute decay of the stone, triggering differential thermal expansion of different materials, fracturing, spalling or materials loss, as well as long-term effects, such as micro-cracks or changes in surface composition leading to further decays [34].

Another deterioration factor specific to the Anthropocene is represented by the graffiti. Present all around researchers, graffiti affect the stone of cultural importance and are particular difficult to counteract, as the graffiti associated materials include a series of agents (paints, polyurethanes, lacquers, enamels, chalk, lipstick, wax, adhesives, etc.) that induce most often a chemical degradation but also the physical decay of the stone [35]. More than that, the removal of the graffiti can lead to subsequent degradations, including the use of abrasive materials that leads to surface alterations, chemical contamination, or mineralogical alterations [36].

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