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Morphology And Deterioration Of Sandstone

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Özet

Kumtaşı, yapım teknolojisinin oldukça farklı olduğu 19. yüzyıl'daki Endüstri Devrimine kadarki dönemde, Türkiye'de ve Avrupa'da oldukça yoğun kullanılmış bir yapı malzemesidir. Yığma yapılarda özellikle yüzey kaplaması olarak ve kesme taş biçiminde kullanılmış olan kum taşı, içinde bulundurduğu granüllerin ve bağlayıcıların kompozisyonuna bağlı olarak çok farklı yapısal özelliklere sahip olabilmektedir.
Bu çalışmanın amacı, ülkemizde ve dünyada büyük bir yapı stokunda bulunan kumtaşının, 'morfolojisinin ve geçirdiği bozulmaların sebep ve biçimlerinin' anlaşılmasına yönelik bir araştırma ortaya koyarak tarihi yapılardaki kumtaşının bakım ve onarımı çalışmalarına katkıda bulunmaktır.

Abstract

Sandstone was a widely used building material in Turkey and Europe since Industrial revolution in 19th century, when the building technology was completely different. Sandstone, which was used in masonry buildings especially for cut-stone facing, may vary in physical characteristics according to the composition of granules and cementing material it contains.
The aim of this study is to present a research intending to make a statement on *'the morphology and causes and forms of deterioration'* of the sandstone, which exists in a wide building stock in Turkey and the world and make a contribution to the studies on maintenance and repair of sandstone.

Keywords: *Building Materials, Sandstone, Morphology of Sandstone, Deterioration, Causes of Deterioration.*

1. Morphology of Sandstone

The sedimentary rocks are formed from water-borne or airborne debris. In the case of sandstones, deposits of silica granules, usually from granitic rocks, are consolidated with an amorphous silica or calcium carbonate cementing matrix, often in conjunction with aluminium or iron oxides. The properties of sandstones depend largely upon the cementing matrix, as the silica granules are virtually inert [ ].

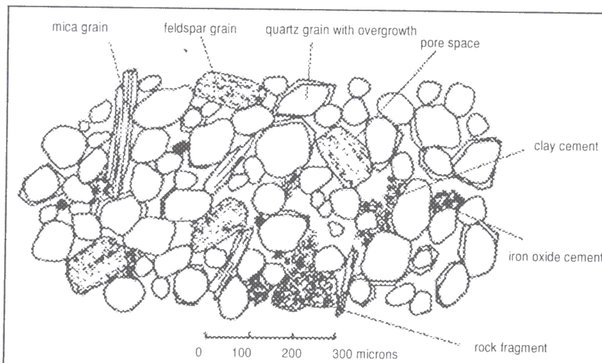

Fig. 1 Structure of a typical sandstone (Andrew, 1994).

A sandstone, by definition, is a rock in which the dominant mineral grain is quartz between 2 to 0.07 mm in diameter. It is formed by the lithification of a sand made up predominantly of rounded quartz grains. The word sand is commonly used to indicate a number of materials. The grains forming the beach at the sea, river or lake side are popularly referred to as sand regardless of their nature. However, a sandstone made up

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of the broken fragments of shells would be classified as a limestone if lithified. Sands made up of grains of the mineral zircon, volcanic ash or corundum are known. Coral sands are common in some parts of the world. Olivine sands are found in the bay of Naples.

Commonly the grains have been naturally cemented, and the cementing material is deposited on the surface of the grains where it partially or completely fills interstices between the grains. If the cementing material is quartz and the original sand indurated with it, a hard, though resistant rock termed a quartzite is formed. The well-known sarsens of Southern England provide an outstanding example of quartzite. There are quartzites, which are igneous and metamorphic in origin. The term quartzite describes the type of rock. It should not be used to imply a mode of origin [ ].

The type of inter-granular cement determines the physical characteristics of sandstones. There are four common cements- silica, limonite, calcite, and clay minerals. Silica-cemented sandstone, even though porous, may resemble a quartzite, in its high hardness, strength, and resistant to decay. Sandstone cemented by limonite is soft to work in a fairly dry climate it will season to a harder, stronger rock, resistant to weathering and chemical disintegration. Calcitic cement is susceptible to the same kinds of chemical decay that affect limestone, and sandstone containing it may be greatly weakened. Clayey cement absorbs water, and sandstone containing it is easily broken, either by freezing or because clay minerals form poor inter-granular bonds.

Inhomogeneities resulting from interbedding are important to conserve in checking sandstone formations for us as building stone. Adjacent layers may differ considerably in type of cement or plagioclay and mica content, or shale beds may be intercalated, if so, the sandstone, whether soft or hard, may be unusable for buildings. Also, the bedding may be too thin for usable blocks. Such variation can be very subtle, and close observation is needed. Because the porosity of commercial sandstone for building use ranges from 2 to 15 percent, the permeability will be fairly high and the stone will stand up to decay only if interbedded layers are not permeable. Quarrying of sandstone is often stopped in winter because water deep inside fresh blocks would freeze and split them, and freezing of near-surface water could cause spalling [ ].

2. Natural Forms of Sandstone

Calcite is a common cementing material and may give a crystalline texture and appearance. If sufficient calcareous cement is present, the sandstone is known as a *calcareous sandstone*. Many sandstones are cemented by one or more of the iron compounds, normally the red iron oxides or the brown iron hydrates, or both. They are known as *ferruginous sandstones*. Usually these are light red to deep brown in colour. The colour is caused by the nature and amount of iron cement present. When iron minerals are present in substantial amount, the sandstone may be called *carstone*. The mineral gypsum is a less frequent cementing medium. The mineral dolomite is more commonly found as discrete grains and not as a cement. When it is present either as cement or as grains, the stone is termed a *dolomitic sandstone*.

Rarely are sandstones pure, that is made up solely of quartz grains with silica cement. Other mineral grains, as distinct from the mineral-cementing medium, are present in greater or lesser amounts. Feldspar, commonly in a particular chemically decomposed state and derived from a disintegrated granite, may be present in considerable amounts. If it makes up a third or more of the rock the name arkose is used. Most arkoses are terrestrial deposits. Flakes of mica lead to a micaceous sandstone. Grains of the mineral glauconite (a complex potassium, iron silicate, $K(Fe, Mg, Al)_2(Si_4O_{10})(OH)_2$), present as small, rounded, green-coloured aggregates give the rock, particularly when wet, a green cast. The rock is termed a *greensand* when glauconite is present in any quantity. Other minerals such as gypsum and barytes may rarely be the cementing medium but may locally be present in noticeable amounts. Clayey material occurs in some sandstones and, if present in quantity, is not a desirable constituent because *argillaceous sandstones* are susceptible to frost action. All these cementing materials were carried into the original loose, incoherent sand by circulating waters. A sandstone is produced by deposition of material from solution to bind the sand grains together.

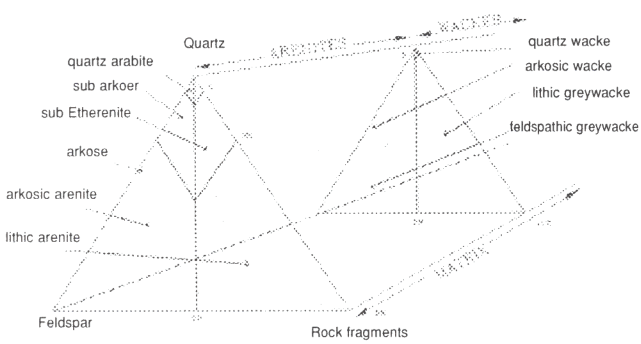

Fig. Calssification scheme for sandstones (Pettijohn, Potter and Siever, 1973 and Greensmith, 1979)

In some sandstones most of the individual grains are well sort, that is they are all about the same size and are rounded. This is a reflection of the mechanical erosion, which they have suffered. Larger pebbles may occur. If the grains are angular, the rock is then termed a *grit or gritstone,* and it is normally, but not necessarily, coarse grained.

The term gritstone has no unique definition. It is often used for a rock or any composition with grain size between 0.5 to 1.0 mm. The mica flakes in a micaceous sandstone are commonly concentrated along bedding planes with their long axes aligned parallel to the bedding. The rock is fissile and will readily split along these planes. If the bedding planes are closely spaced, splitting produces a *flagstone.* The name is believed to be derived from *flagstone*, a name given by the Vikings to the flat stone which they found in Scotland. Some flagstones owe their fissility to thin layers of clay material. Commonly flagstones show ripple marks and suncracks. Sandstones may contain fossils.

Local concentrations of mineral matter, commonly but not always the same as the cementing material may form around a centre or nucleus after the sediment was deposited. Such growths are known as concretions and result from the solution of material at one point of its redeposition elsewhere. In form concretions may be quite irregular but they are commonly found to be flattened ovals in section. They often lie along the direction of the bedding because water travels more easily along the bedding planes. If concretions are hollow, they may be internally lined with crystals. These types of concretions are called *geodes*. Concretions may also be called *doggers*. Frequently they contain fossils, which originally acted as the nucleus, which triggered the deposition of mineral matter. They are a similar colour to the host rock but usually of a deeper shade [ ].

Sandstone finishes:

Sandstones used for construction purposes can have a variety of different finishes. The nature of the finish influences the way in which soiling is deposited on the surface, and hence the visual appearance of soiled sandstone buildings. Commonly applied sandstone finishes are [ ]:

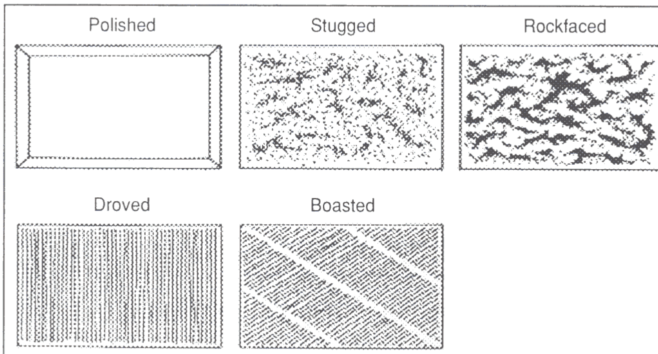

Fig. 3. Different finishes applied to the surface of sandstones. (Andrew, 1994).

Polished: These surfaces are machined to give a smooth even finish, devoid of any tool mark.

Stugged: These finishes are hand-worked using a pointed tool and mallet to produce small indentations over the entire surface.

Rock-faced: Produced by sharp blows to the edge of the stone using a pitching tool and hammer giving a natural rock faced appearance.

Droved: Hand or machine made shallow furrows are produced on the stone to give a regular, grooved finish to the stone.

Boasted: A range of regular patterns can be produced by the use of a pneumatic hand held chisel being heavily applied to the stone surface.

3. Causes and Forms of Deterioration of Sandstone.

Deterioration caused by decay.

There are three main causes of deterioration involving loss of substance. These are:

1. salt crystallisation
2. attack by acidic gases in the air.
3. frost action

Salt crystallisation:

Salt crystallisation is the most important because it is potentially the most damaging. It attacks porous materials irrespective of their chemical composition and often enhances the effects of the other primary causes of decay. Also, it will occur in areas virtually free from frost or acidic air pollution.

A solution of a salt, or mixture of salts, in water is transferred by some means to the pores or frissures of the stone. Under drying conditions, the water evaporates and the salt is deposited on the surface of the masonry, within its pores, or in both positions. A salty growth of florescence appearing on a surface is known as *efflorescence*. Crystallisation that occurs invisibly within the pores of the masonry is called cryptoflorescence. It is not unusual for both forms of florescence to occur together.

Efflorescence is usually regarded as unsightly, but is, in itself, harmless. In contrast, cryptoflorescence causes some pressure to be exerted on the walls of the pores or frissures within the masonry. The magnitude of the pressure will depend partly on the kind of salt involved and partly on the size and arrangement of the pores. The process is not completely understood. However, if the pressure exceeds the internal strength of the stonework, some degree of damage will occur. The damage might be on a microscopic scale at first and cause no more than a slight loss of strength, but, after a sufficient number of cycle of wetting and drying, each lading to a dissolving and recrystallising of the salts, a powdering of the surface will become visible. Occasionally, a large scale fragmentation takes place along some powdering. Formation of powder is, therefore, the diagnostic characteristic of crystallisation damage to masonry.

Crystallisation cycles may occur, not only by direct wetting, but also by the changes of relative humidity of the air. The relative humidity at which a salt or mixture of salts will just begin to pick up water from the air is known as the *equilibrium humidity* (EQRH) of the salt or mixture. Change of temperature is the third way that salt crystallisation can occur through. So, once potentially harmful salts get into the pores of stone, there are at least three ways in which crystallisation damage might occur. This damage will continue to occur indefinitely.

The rate of decay induced by salt crystallisation will depend not only on the types of salt involved and the frequency of the crystallisation cycles, but also on the resistance offered by the stone. Clearly, the smaller the proportion of pore space in a piece of masonry, the better will be its chance of surviving salt crystallisation attack.

Sandstones vary in their resistance to salt crystallisation and the size of the pores also plays an important part in determining their resistance. However, the relationship is not quite so clear-cut as it is with limestones.

Sources of Salts: The possible sources of salts; sea, winter salting of the roads, meat preserving in old times, fired-clay bricks, some preparations for cleaning external walls, rain-washings from limestone or magnesian limestone that contain sulphates.

Decay caused by acidic gases in the air:

Over most of the highly industrialised parts of the world, the air is polluted with small particles of carbon or tar products and with acidic, sulphur-based gases. These are produced by the combustion of solid fuels and oils by industry, transport and domestic heating systems. Various industrial processes put other particles into the air. These, along with transport vehicles, produce nitrogen compounds that almost certainly add to the thunderstorm production of nitrogen-based acids. Air pollution is an important cause of decay in building stones in the industrialised world, but where pollution is low, the effects will be minimal.

The majority of sandstones consist of grains of quartz (a crystalline form of silica SiO_2), cemented together by silica in a less well crystallised form. Iron oxides or hydroxides are sometimes present in the cement and the quartz grains are sometimes accompanied by grains of feldspars and micas. Quartz-based sandstones are very resistant to the sulphur based acids in the air, but they can become very dirty. They tend to be dirtier in the rain-washed areas than in the sheltered parts of buildings. In this sense their behaviour is quite different from that of limestones or marbles. Very occasionally, sulphur-based acids in the air will attack one of the iron compounds in a sandstone and temporarily convert it to a soluble form. This can then migrate to the surface of the stone, where lime, derived perhaps from mortar reconverts it to a rusty-looking insoluble form. Such deposits can remain unnoticed beneath the soot layer until the sandstone is cleaned by a mechanical or chemical process.

In rural areas leaching may be principally due to carbonic acid formed by the absorption of carbon dioxide into the rainfall. This carbonic acid will have no effect on siliceous stones, but it must be appreciated that a sandstone with a carbonaceous matrix must be considered as a carbonaceous stone as it will be affected in the same way as limestones by leaching in the form of bicarbonate. During dry periods, the bicarbonate will decompose to redeposit the carbonate so that leaching tends to involved redistribution of carbonate and its concentration at the evaporation surface. As a result, the surfaces tend to become progressively denser, whilst the stone at the limit of rain absorption will tend to become progressively weaker. Naturally this acid will attack the smaller crystallites in particular and, as there often comprise the cementing matrix in both limestones and sandstones, the stone may become friable in the area affected by leaching. Spalling damage often results through this surface densification accompanied by weakening beneath the densified surface [ ].

Calciferous sandstones, which are defined to contain calcite that does not take part in the cementing process, are attacked by sulphur-based acids in the air. These sandstones weather more severely than limestones in regions of high air pollution because the dissolving of a small amount of calcite will release many sand grains. Where the stone is heavily rain-washed, the surface will steadily powder away. When the stone is not heavily rain-washed, the acid attacks some of the calcite converting it to the more soluble gypsum. Some of the gypsum is drawn towards the surface in solution and redeposited as the moisture dries out again. This produces a weakened layer roughly 4 mm below the surface of the stone that blocks the pores of the surface layer. Changes of temperature cause expansion of the unrestrained gypsum and create stresses that tend to break the gypsum-rich layer from the underlying stone.

Dolomitic sandstones, which are cemented with dolomite, generally withstand an acid-polluted atmosphere better than calcareous sandstones, particularly when there is a lot of cementing material present. This is probably because dolomite is much less attacked by acids than calcite. When a dolomitic sandstone seems to respond like a calcareous sandstone, the cement probably contains calcite as well as dolomite.

Calciferous sandstones, where calcite plays no part in the cement, behave very like calcite-free sandstones, providing there are no complicating factors like the presence of clay. Sandstones containing substantial amounts of clay are known as argillaceous sandstones and have very poor resistance to weathering agencies. They tend to lose strength when wetted and dried, whether or not the air is polluted by sulphur-based acidic gases.

All sandstones, even those in which the grains are cemented by silica, are to some extent susceptible to salt crystallisation attack. One common source of trouble is the calcium sulphate washed from limestone in urban districts by rain. Where sandstones are exposed to the washings they usually decay sooner or later. This is an indirect attack on sandstone by sulphur-based acidic gases in the air.

Contour scaling is a form of decay where a crust of sandstone breaks away at an approximately constant depth of between 5 and 20 mm. The crust follows the man-made contours of the block. When this phenomenon first recognised, it was found out that the detached surface of the sandstone had become completely blocked with gypsum. This was thought to arise because changes in temperature would affect the choked layer differently because of the high coefficient of thermal expansion of gypsum. It was also thought that the tendency of the unchoked stone to expand when wet and contract when dry would be sufficient to develop the necessary shear forces to lead to fatigue failure. The problem was then to explain how the stone became wet and dry in view of the impermeability of the outer skin. Therefore, on the assumption that the choking of the surface pores of some sandstones leads the development of contour scaling, the phenomenon appears to be related to air pollution.

Decay caused by freezing:

Frost attack differs from attack by salt crystallisation and air pollution in two striking ways: frost damages only those parts of a building that can become frozen when very wet; and damage appears dramatically in the form of cracking. Cracking can result in the production of a few large fragments of stone or many small pieces, but frost attack never reduces the stone to a fine powder or produces blisters. Its effects are thus distinctive from those of salt crystallisation or to attack by sulphur-based acids.

Frost damage to stonework takes one or two forms. The commonest form involves the separation of a wafer or lens-like piece of stone from the most exposed surface of the block. The second and less common form of attack, the block of stone is often rendered useless, apparently in one single action. Cracks can radiate in many directions and a block can be reduced to several smaller blocks. This kind of decay is associated with multi-directional cooling of stone.

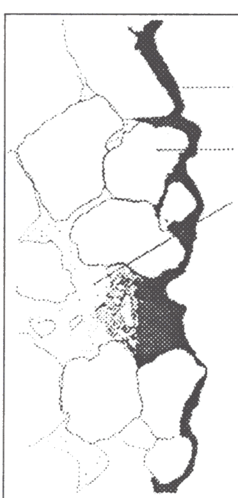

Fig. 4. Typical Example of sandstone soiling.

The effects of frost damage are different if the stone has very marked weaknesses along its natural bedding planes. This can distort the pattern of radiating cracks that develop in the second form of frost damage and it might be mistaken for frost damage of the first kind.

The pore structure of a stone plays an important part in determining its resistance to frost. The fine-pored types of stone being more susceptible than the coarse-pored types. Pore structure has a similar effect on the resistance of stone to salt crystallisation and acidic gas attack.

Unlike crystallisation damage, which can affect all classes of porous stone, frost damage occurs much often in limestones. In long-term tests blocks of stone measuring 100x50x50 mm were exposed standing on end in trays that became filled to a depth of 50 mm each winter. The results after up to 22 years exposure at Garston, Watford, Hertfordshire, England were; limestones failed, 63,5 %; sandstones failed 8 %. Later unpublished results showed sandstones to be even more resistant.

Deterioration caused by staining

While the word decay implies a loss of substance, the word staining implies and undesirable addition of some material to the masonry. Most staining of masonry involves metal corrosion, but other factors are also important.

Effects of tarry pollutants.

The blackening of stonework is caused by particulate air pollutants, which consist of carbon and associated tarry matter. In particularly sheltered parts of limestone walls, these pollutants become cemented on to the wall by gypsum, formed as a result of chemical attack on the limestone by sulphur-based acids. Because gypsum is slightly soluble in water, any dirt that adheres to rain-washed areas of limestone is regularly removed.

Sandstones behave rather differently. The particulate pollutants are very firmly held by the sandstones even where the stone is washed by the rain. Artificial washing with water will not remove them. Tarry matter penetrates the pores of sandstones quite deeply. Artificial washing with using special cleaning agents is possible, but tarry stains tend to remain. Fortunately, the average sandstone is darker than the average limestone and the staining is less obvious and more readily accepted.

Rain washings from limestones:

Rain washings from the exposed parts of a limestone building may be deposited on darker porous material such as another limestone or a sandstone or brickwork. Pale-coloured stains on sandstones can be very disfiguring. They can also cause crystallisation damage, unless the stones or bricks are highly resistant.

Effects from rising damp:

Absence of a damp proof or a defective damp proof course let rising of coloured matter from soil and subsoil, solved in ground water, to the base courses of the building and cause staining. When soluble salts are present, as they usually are in soil water, efflorescence will occur and pitting or powdering might add to the unattractive effect.

Effects from mortars containing hydraulic lime or Portland cement:

There are numerous records of the staining of stonework by alkaline solutions leached from fresh mortars based on Portland cement or hydraulic lime. The stain is always brown. Rich Portland cement mortars are unlikely to be used in the conservation of stone buildings, but hydraulic lime mortars are often thought to be suitable. It would be advisable to carry out a staining test before using hydraulic lime mortars.

Effects from copper and its alloys:

After many years' exposure to town air, copper acquires a stable patina, consisting of copper sulphate, otherwise, copper exposed near the sea acquires a patina consisting of copper chloride. During patina formation, copper sulphate or copper chloride presumably gets solved in water. This solution remains on the mortar or stone as a stain.

Effects from iron and steel:

Rust formed by the action of water and the atmosphere on iron and steel, produces the worst kind of staining on stonework. Rust is virtually soluble in water and its deposition on stone masonry some distance from the exposed iron and steel is not completely understood. Rust stain is known to be more intense than other stains and more difficult, sometimes impossible to remove. So, avoiding rust occurrence is the most effective precaution for it [ ].

Iron staining of sandstones:

Fluid movement within the body of a sandstone over many years dissolves and alters minerals and may re-precipitate them on, or close to, the surface of the stone as evaporation takes place. If the minerals leached from within the stone are dark coloured (such as those containing iron and manganese) their redeposition at the surface can cause aesthetically displeasing staining. When buildings are cleaned this staining can become more noticeable. The degree to which weathering and soiling affect sandstones depends on their mineralogy [ ].

Other causes of deterioration

Wind erosion:

Ruins, cloisters or projections of buildings in arches or alleys are the features that wind passes over at increased velocity. In nearly all cases, the stone is a limestone which will accumulate calcium sulphate because of air pollution, or a sandstone in a coastal region. Hard driven rain will wet the stones thoroughly; and dry wind flowing past will dry them rapidly. These conditions favour salt crystallisation attack. The additional furrowing seen in some sandstones is caused by the different resistance to crystallisation attack shown by adjacent thin beds in the stone.

Heating and cooling and wetting and drying:

Thermal expansion on the heated side cause internal stress within stone. Repeated heating-cooling cycles affect the structure of the stone. Wetting and drying is an inevitable part of the process leading to salt crystallisation damage to stonework. Porous stones expand when wetted and contract on drying. The theory is that fatigue failure must occur, because of shear forces that will frequently arise along any plane seperating the wet form from the dry material.

The approximate thermal and moisture movement of sandstone and other masonry materials are below (Honeyborne, 1990):

Material	*Thermal movement (0/000 for 10 º C)*	*Dry to wet movement (0/000)*
Porous limestones	0.028	0.083
Marble and dense limestones	0.038	0
Granite and other		
Igneous stones	0.10	0
Slate	0.11	0
Sandstone	0.11	0.67
Concrete (dense)	0.11	0.33

The influence of aspect upon sandstone weathering and the role of climatic cycles in flaking and scaling is examined by a group of researchers from University of Wolverhampton. They found out that aspect has a marked influence upon the rates of temperature and relative humidity change, and the occurrence of heating-cooling and wetting-drying cycles. South and west aspects experience a greater occurrence of these cycles than north and east aspects. These cycles cause stresses to the stone which may cause deterioration. Individual forms of flaking and scaling are influenced by aspect in different ways. Black flaking and scaling occur in greatest quantities on the south and west aspect. Blackening of the stone may increase rates of temperature change, and the occurrence of heating-cooling and wetting-drying cycles. Therefore, these factors may be involved in the flaking and scaling of blackened stone [ ].

Fire:

A building fire can have four relevant effects on stone work: blackening, shattering, decomposition and oxidation. Sandstones tend to suffer more than limestones then their surfaces are rapidly heated, probably because their main component, quartz, undergoes a sharp crystalline change at 573 º C.

Chemically induced expansions:

Some expansions of building materials are caused by chemical changes in masonry itself. This cannot happen unless there has been some error in design or construction. The causes of expansion may be: rusting of iron or steel, dead-burnt magnesium limestones,`reaction between a solution of calcium sulphate and a Portland cement-based mortar, large amounts of calcium sulphate additions to cement, alkali-aggregate reaction.

Deterioration caused by living organisms:

Trees, climbers and creepers:

Trees of some fast growing species can progressively lower the average moisture content of clay soils and cause sufficient shrinkage to damage foundations of nearby buildings. Growth of trees and climbers and creepers should be removed as quickly as possible, if damage to the structure is to be avoided.

Smaller flowering plants, ferns and mosses:

The presence of these plants indicates that soil-like dust is available for the plants to grow in. They may indicate that joints in the stonework should be repointed. If the wall is unduly wet moss may be present. Ferns occupy an intermediate position as indicators, because some need damp conditions and other can thrieve in moderately dry ones.

Algae:

Algae, a group of plants producing most of their plants by photosynthesis, may multiply rapidly under he right conditions. The green appearance imparted to the stone by algae is often considered to be disfiguring. Their appearance is made much worse in an urban environment when dirt readily becomes entrapped in the algal mass.

Fungi:

Fungi that do not have the ability of producing their own food, need some organic food for living, So, they need waste of other organisms, decaying leaves, bird droppings etc. for living on the stone. Fungi can produce organic acids such as oxalic and citric acids. Both of these acids are harmful for limestones.

Lichens:

Lichens, which are the symbiosis of fungi and algae, are more important contributors to stone decay than either type of organism on its own. Lichens have been known to attack sandstones and even basalts and granites, beside limestones. It is widely believed that the damage is often the result of surface stresses induced when the lichen shrink on drying after remaining wet for long periods.

Bacteria:

The bacteria cause decay by producing chemicals and do not significantly change the appearance of stone unlike algae, fungi and lichens. The groups of bacteria most likely to be involved are those that can oxidise sulphur or one of its compounds to form sulphuric acid which attacks limestone directly, those that oxidise ammonia in the air to form nitric acid, which also attacks limestone directly, and those that produce organic acids with the power to dissolve silicates in sand stones. The decay caused by bacterial products is incomparable with decay caused by salt crystallisation, air pollution and frost.

Birds and Bees:

The decay of birds is caused mainly by the accumulation of their droppings and nesting materials. These can form compost, which breaks down as a result of bacterial action and releases acids, which will attack limestone and calcareous sandstone.

The mason bees also, can harm stonework. They bore holes in soft stone to provide a safe refuge. The stones affected are mainly loosely bonded, possibly argillaceous sandstones [10].

References

[1] Richardson, B. A., (1990), *"Natural Stonework"*, p.21-22, *The Maintenance of Brick and Stone Masonry Structures,* Ed. A.M. Sowden, London, E. & F.N. Spon.

[2] Dimes, F. G., (1990), *"Sedimentary Rocks"*, p. 61, *Conservation of Building and Decorative Stone,* v.1, Eds. John Ashurst and Francis G. Dimes, London, Butterworth-Heinemann Series in Conservation and Museology.

[3] Robertson, E. C., (1982), *"Physical Properties of Building Stone"*, p.82, *Conservation of Historic Stone Buildings and Monuments,* Washington D.C., National Academy Press.

[4] Dimes, F. G., (1990), Ibid., p.61,62.

[5] Andrew, C., (1994), *"Stone Cleaning, A guide for practitioners"*, Technical Conservation, Edinburgh, Research and Education Division, Historic Scotland, p.8.

[6] Richardson, B. A., (1990), *"Deterioration of Materials; Stonework"*, p.122, *The Maintenance of Brick and Stone Masonry Structures,* Ed. By A.M. Sowden, London, E. & F.N. Spon.

[7] Honeyborne, D. B., (1990), *"Weathering and Decay of Masonry"*, p.153-163, *Conservation of Building and Decorative Stone,* v.1, Edited by J. Ashurst and F. G. Dimes, London, 1990, Butterworth-Heinemann Series in Conservation and Museology

[8] Andrew, C., (1994), *"Stone Cleaning, A guide for practitioners"*, Edinburgh, Technical Conservation, Research and Education Division, London, p.8,16.

[9] Halsey, D. P.; Dews, S. J.; Mitchell, D. J.; Harris, F.C., (1996), *"Influence of aspects upon sandstone weathering: the role of climatic cycles in flaking and scaling"*, p.849-858, *Proceedings of the 8th International Congress on Deterioration and Conservation of Stone,* v.2, Berlin, 30 Sept.-4 Oct. 1996.

[10] Honeyborne, D. B., (1990), *"Weathering and Decay of Masonry"*, p.163-169, *Conservation of Building and Decorative Stone,* v.1, Edited by John Ashurst and Francis G. Dimes, London, Butterworth-Heinemann Series in Conservation and Museology.

Ashurst, J.; Ashurst, N., (1988), *"Stone Masonry, English Heritage Technical Handbook"*, v.1, London, Gower Technical Press, p.44, 45, 49, 53, 58.

Clifton, J. R. ;Frohnsdorff, G. J. C, (1982), *"Stone Consolidating Materials: A status report"*, p.290-291, Conservation of Historic stone Buildings and Monuments, *Report of the Committee on conservation of Historic Stone Buildings and Monuments*, , Washington, D.C., National Academy Press.

Torraca, G., (1988), "General Philosophy of Stone Conservation", p.247-248, The Deterioration and Conservation of stone- studies and documents on the cultural heritage,no:16., Eds. L. Lazzarini, R. Rieper, UNESCO