DETERIORATION FACTORS OF DELICATE MATERIALS

SCHÄDIGUNGSFAKTOREN EMPFINDLICHER MATERIALIEN

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SUMMARY

The scope of the paper is to provide information about the factors that cause degradation, deterioration and corrosion of a number of cultural heritage materials. This information is useful for identifying agents that damage cultural heritage materials. The three main degradation mechanisms considered are physical, chemical and biological mechanisms. Physical degradation factors discussed are temperature, relative humidity, ultraviolet and infrared light. Chemical deterioration factors mainly include atmospheric pollutants that cause chemical reactions in correspondence with enhancing climate conditions. The effects of both indoor and outdoor pollutants on material degradation are described. Indoor pollutants include organic acids, sulphides, their compounds, etc. Outdoor pollutants consist of nitrogen oxides, ozone, sulphides, their compounds, etc. Biological degradation factors are biological agents such as fungi, bacteria or other microorganisms. For each material the causes of degradation are explained and the degree of its sensitivity to deteriorating factors are defined.

ZUSAMMENFASSUNG

Der Fokus dieses Dokuments besteht darin, Informationen über die Faktoren bereitzustellen, die die Ursache für den Abbau, die Schädigung und die Korrosion einer Reihe von Materialien des kulturellen Erbes sind. Diese Informationen sind nützlich, um die Stoffe zu identifizieren, die Materialien des kulturellen Erbes beschädigen. Die drei wichtigsten betrachteten Abbau-Mechanismen sind physikalische, chemische und biologische Mechanismen. Die diskutierten physikalischen Schädigungsfaktoren sind Temperatur, relative Luftfeuchtigkeit, ultraviolettes und infrarotes Licht. Chemische Schädigungsfaktoren umfassen hauptsächlich Luftschadstoffe, die Ursache für chemische Reaktionen sind in Verbindung mit fördernden Klimabedingungen. Die Auswirkungen von Innen- und Außenschadstoffen auf den Materialabbau werden beschrieben. Zu den Schadstoffen in

Innenräumen gehören organische Säuren, Sulfide, ihre Verbindungen usw. Schadstoffe im Freien bestehen aus Stickoxiden, Ozon, Sulfiden, ihren Verbindungen usw. Biologische Schädigungsfaktoren sind z.B. Pilze, Bakterien oder andere Microorganismen. Für jedes beschriebene Material werden die Hauptschädigungsmechanismen und die Sensitivität gegenüber entsprechenden Faktoren beschrieben.

1. INTRODUCTION

The objective of this paper is to provide information about the causes of degradation, deterioration and corrosion of a number of materials related to the cultural heritage sector. Corrosion or degradation involves the deterioration of a material when exposed to an environment resulting in the loss of that material. Among many corrosive environments, air and humidity, polluted atmospheres, gases such as chlorine, ammonia, hydrogen sulphide, sulphur dioxide, oxides of nitrogen, acids and alkalis may be mentioned. There are different degradation mechanisms of materials from different viewpoints. In general, a) physical, b) chemical, c) biological, and d) their combination are considered as the main mechanisms through which degradation or deterioration of cultural heritage materials occurs. The coupling effects of these mechanisms can accelerate the rate of degradation.

In physical degradation mechanism, temperature and relative humidity have a key role and can accelerate the process of degradation. Light, i.e. natural light, ultraviolet (UV) and infrared light, has also degradation effects.

In chemical degradation mechanism, the material reacts chemically with materials present in the environment. Atmospheric pollutants are sometimes necessary for a chemical reaction. Exposure to chlorides, and carbon dioxide, and calcium leaching are examples of chemical degradation. Pollutants can be classified from different viewpoints. In general, atmospheric pollutants can be divided into: i) indoor pollutants, and ii) outdoor pollutants. Indoor pollutants include organic acids, sulphides, etc. Indoor organic acids are emitted from wood species, paints, etc. [1]. Organic acids are organic compounds with acidic properties. Organic acids are weak acids and have a low reactivity with metals compared to strong mineral acids like hydrochloric acid (HCl). The sources of organic acids in museums are wooden materials used for cases, cabinets, etc., and natural woods as well as paints, adhesives and varnishes (Gibson and Watt, 2010). Outdoor pollutants include nitrogen oxides (NO_x), ozone (O_3), sulphides, etc. Nitrogen dioxide (NO_2)

and nitric oxide (NO) are important nitrogen oxide-based pollutants. Important sulphide-based pollutants are hydrogen sulphide (H_2S) and carbonyl sulphide (COS). Inorganic acids such a nitric acid (HNO_3), sulphuric acid (H_2SO_4), carbonic acid (H_2CO_3), sulphurous acid (H_2SO_3) and nitrous acid (HNO_2) are products of pollutants that cause material degradation. Inorganic acids are resulted from one or more inorganic compounds, and range from strong acids such as perchloric acid ($HClO_4$) to very weak acids like boric acid (H_3BO_3), and are soluble in water and insoluble in organic solvents [1, 2]. The main sources of nitrogen pollutions in the atmosphere are emissions from fossil fuel combustion from vehicles and power plants, and agriculture. The main sources of sulphur-based pollutants in air are the burning of fossil fuels such as coal, the production and burning of oil and natural gas, and industries producing and using sulphuric acid [3].

In biological degradation mechanism, mainly organic materials are degraded by biological agents such as bacteria, fungi or other microorganisms. For example, parchment, stone, textiles, varnishes and wood are vulnerable against microorganisms.

Materials studied in the paper are: 1) organic materials including amber, bone, ivory, leather, paper, parchments, textiles, varnishes and wood, 2) inorganics materials including ceramics, glass, pigments, and stone, and 3) metallic materials including copper, iron, lead, silver, steel and zinc.

The causes of degradation are explained for each material. Suitable temperature and relative humidity are explained for the materials. In general, for temperature and relative humidity a number of reference sources exist. The causes of degradation are explained for each material. In addition, suitable temperature and relative humidity for cultural and museum objects are explained. General provisions of environmental conditions for museums are provided by a number of guidelines such as AIC [4], AICCM [5] and Bizot [6]. Bizot guidelines for hygroscopic materials, such as canvas paintings, textiles, ethnographic objects and animal glue, state that the temperature should remain between 16°C and 25°C and the relative humidity should be kept between 40% and 60% with maximum fluctuations of ±10% per 24 hours. According to AICCM, for storage and display conditions the temperature should be between 15°C and 25°C with a maximum fluctuation of ±4°C per 24 hours. The relative humidity should be between 45% and 55% with maximum fluctuations of ±5% per 24 hours. Based on AIC recommendation, for most cultural materials the acceptable temperature is between 15°C and 25°C, and the acceptable relative humidity is between 45% and 55% with a maximum fluctuation of ± 5%.

2. ORGANIC MATERIALS

2.1 AMBER

Physicochemical environment factors, such as oxidation accelerated by heat and light degrade amber [7]. Pollutants, relative humidity, oxygen and energy are three degrading environmental factors [8]. Amber surface degradation is caused by air pollutants such as volatile biocides. Quick chemical disintegration results from heat and UV, two types of energy. Degradation of amber appears in many forms. Darkening, in particular of transparent amber, is common. Cracking, crazing, i.e. coarse surface cracks, or, crizzling, i.e. fine shallow cracks, also appear. Four main causes of damage to amber are: 1) physical conditions, such as relative humidity, light and temperature, 2) cleaning agents, such as ammonia, sodium bicarbonate, and sodium hypochlorite, 3) biocides, such as naphthalene, paradichlorobenzene, camphor, DDVP (dichlorvos) and hydrogen phosphide, and 4) common air pollutants, such as ammonia, formic acid, hydrogen sulphide and acetic acid [9].

2.2 BONE

Many types of agents may alter the surface structure of bone in addition to its molecular chemical compositions [10]. Highly alkaline environments change the most organic components such as bone. Bone can be corroded by highly alkaline sediments [11]. Sediments of pH 4 or below may corrode bone [12]. Bone is also sensitive to acids. It has been shown that concentrated hydrochloric acid of pH 1.66 has corroded bones significantly more than solutions of pH 2.35 [12]. Acetic acid may have damaging effects on bone at high concentrations [14].

The best temperature for bone is less than 25°C and the best relative humidity is between 45% and 55%. Bone should be prevented from direct sunlight or spotlight. It should not be exposed to illumination of more than 150 lux with a maximum ultraviolet (UV) of 75 µW/lm [15].

2.3 IVORY

Ivory is very vulnerable to changing environmental conditions such as fluctuating relative humidity and changing temperature. Ivory is a hygroscopic material and, hence, by changing relative humidity it absorbs and releases moisture and swells and shrinks. Cyclic fluctuation of relative humidity causes cracking and warping of ivory [16]. Changing temperature causes the fluctuation of relative humidity, which causes the above-mentioned damages to ivory. High relative humidity should be avoided in order to prevent biological activity and warping of ivory. Too low relative humidity should also be prevented to protect ivory against warping and cracking. The best temperature is not more than 25°C and the best relative humidity is between 45% and 55%. Direct sunlight or spotlight damages the ivory. The maximum illumination is 150 lux with a maximum ultraviolet (UV) of 75 µW/lm [15]. Acetic acid may have damaging effects on ivory at high concentrations [14].

2.4 LEATHER

Degradation of leather is in the form of disintegration of its structure, often related to the condensation of tannins by acids or oxidation. Because of temperature fluctuations, leather loses its water vapour absorption and becomes brittle [17]. The main causes of degradation of leather are hydrolysis and photooxidation [18]. A type of protein called collagen is the main component of leather. Its main structural units are amino acids linked by peptide bonds to polypeptide chains. The common reasons of disintegration of collagen are oxidation, hydrolysis and denaturation. Collagen chain is split into acid amides or keto acid derivative by oxidation. In the presence of light, Sulphur dioxide is converted to Sulphur trioxide on the surface of leather. Sulphur trioxide in the presence of oxygen may form Sulphur dioxide and ozone, which is a strong oxidizing agent. There is little report about carbon dioxide to cause deterioration of leather. Oxidation increases at high temperature and low relative humidity, light and air pollutants. Leather is degraded by acid hydrolysis. This is common for leather because acid gases such as SO_2 and NO_x and corresponding acids are formed in the atmosphere [19].

2.5 PAPER

Environmental factors, such as temperature, relative humidity and pH have negative effects on paper [20]. In addition, air pollutants such as nitrogen oxides, Sulphur dioxide and ozone are responsible for paper degradation [21]. The acidity of paper is increased by pollutants such as NO_2 and SO_2, which decrease the mechanical properties of paper. Lignin-papers absorb pollutant, which causes discolourisation [22]. Nitrogen dioxide (NO_2) is responsible for yellowing of some types of papers [23]. Studies indicate that NO_2 is a much stronger pollutant for paper either than SO_2 or O_3 (ozone). In addition, adding SO_2 to NO_2 decreases the effect of NO_2 [22].

Chemical and biological deterioration of paper increases by relative humidity of more than 60%. The maximum relative humidity should be 50%. The rate of degradation of paper decreases at low temperature. Where human comfort or cost is required, the maximum temperature is 21°C. Fluctuating of temperature and relative humidity should be prevented [24].

2.6 PARCHMENT

Studies have shown that parchment can tolerate temperature of 40°C at relative humidity of less than 60%. Partial denaturation happens at temperature higher than 40°C. At relative humidity between 60% and 80% both stability and energy distribution between collagens is affected, and by increasing temperature, the thermal denaturation of collagen is accelerated. Considerable damage is occurred to parchment due to relative humidity higher than 80% as well as high relative humidity fluctuations. Dry heating up to 100°C has much more negative effect than humid heating up to 80°C [25].

The suitable relative humidity for parchment depends on the conditions. About 25% relative humidity is the minimum amount that does not cause large stresses in parchment. Relative humidity higher than 40% causes gelatinisation and increased the risk of biological deterioration. Considering the physical, and chemical reaction of collagen and biodeterioration of parchment a relative humidity of 30% is suggested as optimum for storing parchment [26].

2.7 TEXTILES

Most of cultural heritage textiles are made of organic fibres, hence, they are vulnerable to deterioration. The main environmental degradation factors are physical and chemical ones. Physical factors are light (natural or ultraviolet light), humidity and heat, which cause colour alteration and fragility. Chemical factors include atmospheric pollutants. For example, noxious gases such as sulphur dioxide and nitrogen dioxide, acidic agents and oxidising substances damage textiles [27].

A study on textiles on a museum has shown that both low temperature and high relative humidity accelerate the formation of microorganisms and mould. High temperature can cause dehydration of fibres and decrease their strength. Improper light can cause major damage fading the colour, or yellowing uncoloured textiles as well as deterioration of fibres. Ventilation of indoor air for 30 minutes a day prevents the growth of fungi due to high relative humidity. Relative humidity should always be kept less than 70% to avoid mould and shrinkage of textiles. The standard temperature of 21°C is recommended [28].

2.8 VARNISHES

The degradation factors of this type of varnishes are UV, temperature, relative humidity, oxygen and air pollutants [29]. Two natural triterpenoid resins, dammar and mastic, are used as varnishes for paintings. Their main drawback is their yellowing that changes the appearance of paintings [30].

Studies have shown that organic pollutants acetic and formic acids cause damage on dammar, resin mastic, Reglarez 1094, Laropal A81, and dammar with a coating of Regalrez 1094 varnishes. Oxidation had cross linking have been observed, which is an indication of increasing in brittleness of the varnish. The resistance of synthetic varnishes, Reglarez 1094 and Laropal A81 to organic acids was shown to be more than natural resins mastic and dammar [31].

Both mastic and dammar varnishes get damaged by nitrogen dioxide [32, 33]. Ozone causes damage to dammar varnish [32].

2.9 WOOD

The degradation of wood can occur due to different factors such as ultraviolet, infrared light, relative humidity, temperature, atmospheric gases such as oxygen, pollutant gases such as sulphur dioxide and nitrogen dioxide, and other agents such as microorganisms. A relative humidity of 50% and temperature of 21°C are the best conditions for wooden objects [34]. Wood is a natural organic material in which microorganisms and insects inhibit and cause the degradation of wood [35]. Bacteria and fungi damage wood by degradation of cellulose, hemicellulose and lignin. Consequently, the peeling, delamination and discolouration of wood surface in addition to reduction of mechanical properties occur [36].

2.10 SUMMARY ORGANIC MATERIALS

For protection of amber, bone, ivory, leather, paper, parchment, textiles, varnishes and wood the recommended relative humidities are respectively 45-55%, 45-55%, 45-55%, 30-60%, 40-55%, 25-40%, 45-53%, 45-55% and 45-55%, and the best temperatures are respectively 15-18°C, 21-25°C, 21-25°C, 10-21°C, 18-22°C, 10-15°C, 21-23°C, 21-24°C and 20-21°C as shown in Fig. 1 [37].

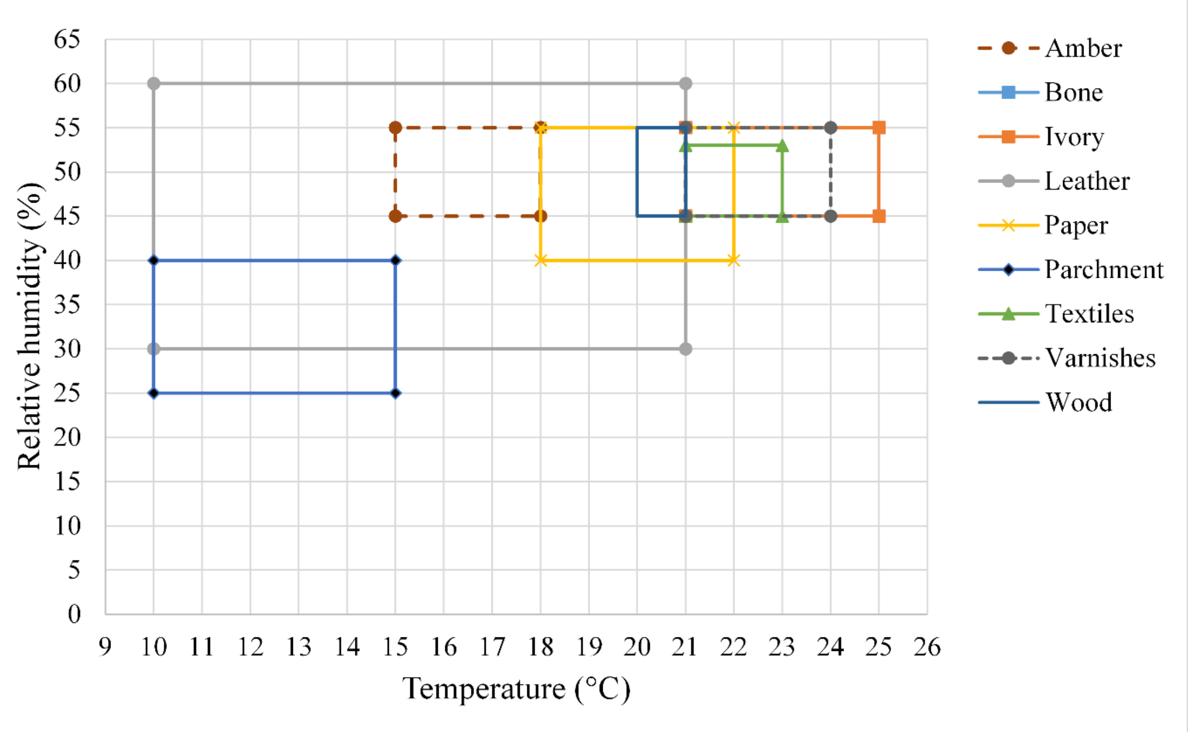

Fig. 1: Recommended relative humidity and temperature for protection of organics materials

3. INORGANIC MATERIALS

3.1 CERAMICS

The formation of salt crystal in porous materials such as stone and ceramics causes damage. The formation of salt efflorescence on porous calcareous artefacts, as a result of attack by organic acids, has been observed for many years. Sometimes crystalline surface deposits forms by reaction of acetic acid pollutant vapour with the material of the object and impurities within it [38]. Acids damage ceramics in different ways. Treatment with HCl results in formation of chromophoric species [39]. The treatment of ceramics with acid may lead to dissolution of calcareous components and slippage, leaching out iron oxides, and damaging lead glazes by nitric acid [40]. Acids cause slip degradation and friability [39, 41]. Treating iron rich ceramic glazes treated with hydrochloric and oxalic acids lead to loss of iron oxides [42].

3.2 GLASS

Pollutants in the environment have a strong effect on glass corrosion [43]. Both strong inorganic acids such as sulphuric acid and nitric acid create by sulphur dioxide and the oxides of nitrogen in the atmosphere, and organic acids have corrosive influence on glass [44]. The combination of relative humidity and unstable glass composition accelerates the corrosion of glass by organic pollutants. Wood in museums can produce pollutants, formic acid, acetic acid and formaldehyde can react with glass and generate crystalline sodium format at glass surface [45] and make structural and chemical changes to glass [46]. In environments with different types of pollutants, the pollutant with the highest acid-ionisation constant dominates the corrosion. The corrosion of glass is accelerated with environmental (temperature and relative humidity) fluctuations. Therefore, the glass must be stored in places with steady state environmental conditions and high temperature and high relative humidity should be avoided [43].

3.3 PIGMENTS

Various causes of the changing of the colour occurred in the pigments of paintings have been identified by many researchers. The causes are attributed to redox processes and/or modification of metal coordination of some inorganic compounds such as the pigments cinnabar (HgS), Prussian blue, smalt (potash glass with colour originating from cobalt ions), copper resinate and verdigris (both green copper organo-metallic compounds). Yellow colour alteration has been shown to be related to different reasons such as the photo-oxidation of original CdS to $CdSO_4$, and photo-reduction of the zinc yellow pigment to ochre-green Cr(III)-compounds [47]. It has been shown that nitrogen dioxide alters the colour of pigments usually to yellow [48].

3.4 STONE

There are several causes for degradation of building stone among which microbiological causes, salt crystallisation, aqueous dissolution, and frost damage are important. General forms of microbiological agents are bacteria, fungi and algae that produce acids and other damaging chemicals that react with carbonate and silicate minerals of stone and deteriorate it [49].

The reaction of air pollutants with stone produces salts, such as calcium sulphate, which is the production of reaction of sulphur dioxide in the air with limestone. Salt crystallisation inside the pores of stone creates stresses that leads to the cracking of stone. Low soluble salts such as calcium sulphate cause the spalling of the surface of the stone [50]. High soluble salts such as sodium sulphate and sodium chloride powder and crumble the surface of stone [51].

4. METALLIC MATERIALS

4.1 COPPER

Copper alloys react with acetic acid and formic acid in high concentrations and high relative humidity [21]. Observations of reaction of copper with formic acid indicates that at 50% relative humidity during 120 days there has been no damage at a concentration of 960 µg m^{-3}, but visual damage has occurred at 9600 µg m^{-3} [52]. Ozone (O_3) has damaging effect on copper in combination with some other pollutants such as NO_2, SO_2 and humidity. O_3 introduction results in an accelerated mass gain that could be related to an increased formation rate of both Cu_2O and $CuSO_4.xH_2O$ all over the surface. Direct evidence of an O_3-induced oxidation process on the copper surface could be seen where precipitated $CuSO_3.xH2O$ was transformed to precipitated $CuSO_4.xH_2O$ [53].

Polished copper gradually tarnishes. This darkening is caused by sulphur-containing gases from pollution, rubber, wool etc. in the air. When copper alloys are exposed to outdoor atmosphere green corrosion is produced.

4.2 IRON

Factors affecting the corrosion of Iron are moisture, acids, and salts. Increasing the relative humidity accelerates corrosion. Acids, with low pH, favours its rusting, whereas higher pH inhibits the degradation of iron. The presence of salts speeds up the process of corrosion. The atmospheric corrosion of carbon steel or weathering steel starts at about 60% relative humidity and is accelerated at relative humidity between 80% and 100% [54]. In order to lower the rate of corrosion of untreated archaeological iron it is recommended to store it below 20% relative humidity [55].

At relative humidity more than 55%, salts on the iron surface absorb humidity from the air and dissolve into the water vapour to make a yellow, brown or orange acidic liquid that corrode iron. For this reason, iron should be stored at low relative humidity, less than 50%. Relative humidity between 50% and 65% does not damage iron provided it does not contain high levels of soluble salts or active corroding. In relative humidity higher than 65%, iron is expected to undergo damage. Temperature and illumination are not expected to corrode iron except when they affect relative humidity [56].

4.3 LEAD

Lead is the most sensitive material for organic acids such as acetic acid and formic acid. It can be affected by formaldehyde at high relative humidity and oxidising agents in the atmosphere. When fomaldehyde is in more oxidizing environments (atmospheres containing hydrogen peroxide) it causes heavy corrosion but in the dark, with no oxidant, there is only very slight tarnish, even at high humidities. This suggests that oxidation is an important control on corrosion by formaldehyde [57].

Lead corrosion is white and often powdery. It can cause pitting. There is a large volume change on corrosion and lead sheets can deform during corrosion. The corrosion products are toxic and should be handled appropriately. The corrosion of lead caused by acetic acid is alkaline lead carbonate, hydrocerrusite. Non-hydrated form cerrusite is also noticeable. In atmospheres rich in formic acid, lead formate is the main result of corrosion, which can be converted to hydrocerrustie over time. The presence of lead formate in the form of paint or varnish is often a cause of corrosion [58]. White corrosion on lead is usually caused by exposure to volatile organic acids such as acetic acid (vinegar). Grey corrosion on lead is usually caused by formic acid.

4.4 SILVER

Atmospheric factors for the corrosion of silver are mainly relative humidity, temperature and airborne pollutants. Besides relative humidity and temperature, gaseous pollutants such as hydrogen sulphide (H_2S), nitrogen oxide (NO_x), sulphur dioxide (SO_2) and ozone (O_3) deteriorate silver. Silver is very sensitive to NH_3, H_2S, Cl_2 and O_3 but relatively insensitive to HCl and SO_2. Oxidising agents such as O_3, NO_2 and Cl_2 can accelerate producing rate of Ag_2S. Main corrosion products are Ag_2S and AgCl [59]. In the presence of sulphide with high concentrations the surface of silver gets tarnished and its colour changes from yellow to violet, blue grey and finally dark grey, is actually the colour of a corroded layer of Ag_2S. Exposure of Ag to UV has been shown to accelerate Ag corrosion [60].

The effect of CO_2, UV and ozone has been proven to accelerate silver corrosion rate [61]. The corrosion of silver increases by increasing the ozone concentration in the environment. Relative humidity is an atmospheric factor that is a cause of silver corrosion. The formation of oxide and corrosion rate depends on the relative humidity such that it has been shown that ozone oxidation of silver happens at 50% relative humidity [59].

4.5 STEEL

Mild steel or plain carbon steel (CS) is vulnerable to corrosion. Weathering steel (WS) is a class of low carbon steel with carbon content of less than it 0.2% of weight that have additional alloying elements mainly, Cu, Cr, Ni, P, Si and Mn totally less than 3 to 5% of weight. Weathering steel has enhanced corrosion resistance because of formation of an adhering corrosion product layer called patina [62]. In moderate aggressive atmospheres with wet/dry cycles, low time of wetness and low amounts of chlorides, less than 6 mg Cl^-/m^2 day, and SO_2, less than 20 mg/m^2 day, a protective rust layer is formed on weathering steel [63].

The corrosion rate of WS exposed to moisture for a long time is the same as CS [64]. Atmospheric pollutants, in particular in industrial and coastal areas, corrode steel. Sulphur dioxide (SO_2) and chlorides change the protective properties of the corrosion layer on weathering steel [65].

4.6 ZINC

A study about the effects of ambient ozone (O_3), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) on the atmospheric corrosion of zinc indicates that O_3 and NO_2 stimulate the corrosion of zinc in the presence of SO_2 in humid air. The damaging effect of O_3 is accelerated at both 70% and 95% relative humidity, while NO_2 causes damage at higher humidity. By reducing the concentration of the pollutant, the effect of O3 and NO_2 on the acceleration of SO_2 oxidation and deposition on zinc increases significantly. In ambient air, the role of O_3, and to a lesser extent NO_2, seems to be important for the corrosion of zinc [3]. Zinc is sensitive to formic acid. It has been shown that the corrosion effect of formic acid on zinc has a low dependency on relative humidity [66].

4.7 SUMMARY METALS

For protection of copper, iron, lead, silver and zinc the maximum recommended relative humidities are 54%, 50%, 30%, 50% and 70%, respectively, as shown in Fig. 2.

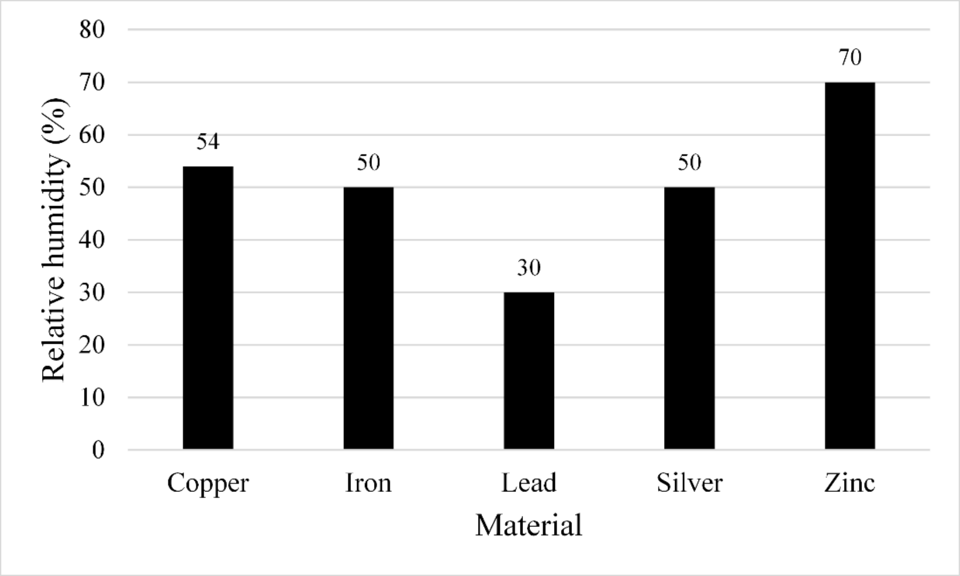

Fig. 2: Maximum recommended relative humidity for protection of metallic materials

5. CONCLUSION

The information about the causes of degradation of a number of materials used in the cultural heritage sector has been provided.

In physical degradation mechanism, temperature, relative humidity, natural light, ultraviolet and infrared light and their combinations can have influence on the degradation of materials such as amber, bone, copper, glass, iron, ivory, leather, paper, parchment, silver, stone, textiles, varnishes and wood. The rate of influence of each factor on each material and the resulted degradation is different. For example, types of degradation are yellowing and crazing in amber, cracking and warping in ivory, brittleness in leather, changing of dimensions and aging in parchment, and colour alteration and fragility in textiles.

In chemical degradation mechanism, a variety of degrading factors and their combinations can have influence each material. Amber is sensitive to ammonia, formic acid, hydrogen sulphide and acetic acid. Bone is damaged by hydrochloric acid and acetic acid. Ceramics and iron are vulnerable to acids in different ways. Lead corrodes because of most organic acids. Leather is sensitive to sulphur dioxide and nitrogen dioxide. Paper degradation occurs by atmospheric pollutants such as oxides, sulphur dioxide and also by ozone. Parchment is deteriorated by sulphur dioxide. Colour alteration and mechanical damage in pigments occurs by inorganic salts and nitrogen dioxide. Atmospheric pollutants such as sulphur dioxide and chlorides are responsible for the corrosion of weathering steel. Stone is attacked by both organic and inorganic acids. Textiles are deteriorated by atmospheric pollutants such as sulphur dioxide and nitrogen dioxide. Varnish is vulnerable to acetic acid, formic acid, nitrogen dioxide and ozone. Wood deteriorates in the presence of oxygen and pollutant agents such as sulphur dioxide and nitrogen dioxide. The corrosion of zinc can happen due to ozone, sulphur dioxide, nitrogen dioxide and formic acid.

In biological degradation mechanism, microorganisms such as fungi and bacteria are deteriorating factors. Parchment is deteriorated because of the degradation of collagen by bacteria, fungi, rodents, etc. The colour alteration of stone is the result of producing pigments by microorganisms. Textiles are vulnerable to fungal degradation. Wood is damaged in sense of peeling and delamination and it is discoloured by microorganisms such as bacteria and fungi.

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