Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
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Journal of Applied Sciences 14 (4): 374-379, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.374.379

Progress Research on Bio-deterioration of Historic Architectural Glasses

Song Gang, Yang Changming and Zhang Aili
College of Architecture and Urban Planning,
College of Architecture and Civil Engineering, Beijing University of Technology,
100022, Beijing, People Republic of China

Abstract: This study attempts to guide and promote the future research on bio-corrosion prevention and cleaning techniques of historic architectural glasses, while there are no domestic relative researches reported now. Firstly, the author demonstrates that the bio-deterioration of glasses does exist according to references and its degradation consequences can not be ignored. It systematically analyzes the recent abroad relative researches and gets the conclusions that there are three main bio-deterioration impacts on historic architectural glasses, i.e., the decreasing in the transparency and thickness of the glasses and changing of the tinct. Then we get the main bio-deterioration forms, the bio-films covering, incrustation mineralization of microbial metabolites and mechanical disruption caused by microbial growth in the micro-fractures on glasses surfaces. Furthermore, the bio-deterioration mechanism of glasses with a visualized figure is given out. We also introduce the latest applications of molecular biology experimental technique in this research field and points out the newly developed glass cleaning techniques, including laser cleaning and the disadvantages both in expensive costs and operations. Based on the above analysis, it also prospects the bio-deterioration research of historic architectural glasses and research of specific domestic regions, researches on reservation cleaning technologies and accelerated laboratory test of bio-deterioration.

Key words: Building materials, corrosion microbiology, historic architectural glasses, architectural heritage reservation, bio-deterioration, molecular biology, glass-cleaning

INTRODUCTION

Modern architectural heritage protection in recent years has become a new hotspot in the urban cultural heritage protection. The Chinese modern architectures are the product of blending, collision between Chinese and western culture, they have rich history and artistic connotation, among them there are a lot of churches and independent of colonial style residential buildings. As they are an indispensable part of the architectural language and the cultural relics such as beautiful window, colored drawing or pattern glass and Mosaic glass construction glass (historical architectural glasses), they ate the important carrier of art architectural heritage value. But now the glass erosion of these art works of Chinese architectural heritage is very serious and the rescue and protection of them are very necessary and urgent. However, we often ignore the deteriorating consequences they are facing.

The degradation mechanism of them, especially the mechanism of microbe degradation research is developed insufficiently. And the past limited research is mainly performed by foreign researchers, the research has been stagnated in recent years and the similar research is almost blank in China. Therefore, the domestic researchers of china should actively carry out targeted degradation mechanism (including the microbial degradation) and cleaning technology development work of the architectural heritage.

MICROBIAL DEGRADATION PHENOMENA OF THE CULTURAL RELIC ARCHITECTURAL GLASS

Definition of glass types and materials in cultural relic building: Glass material is mainly used in doors and windows of the building. And the cultural relic architectural glass discussed in this study, mainly refers to the middle ages and modern European architecture, it is the important part of the cultural heritage. The art glass has an independent artistic value is mainly refers to color glass or glass mosaic.

Medieval stained glass mainly used in 13-15 century has two kinds: One is the rich in sodium glass (which is

Corresponding Author: Yang Changming, College of Architecture and Urban Planning, Beijing University of Technology, 100022, Beijing, People Republic of China

stable, Mediterranean, similar to the traditional roman style) and rich in potassium, calcium of glass (similar to the central European Medieval stained glass) (Garcia-Valles *et al*., 2003). And as known that from the Middle Ages to the Renaissance period, the stained glass is generally applied in the church buildings and they are made of potassium-lime-silicate glass (Carmona *et al*., 2006).

Microorganism degradation phenomenon in cultural relic building glass: The glass microorganism degradation phenomenon is often neglected in the short term; many professionals even think that there does not exist glass degradation problem. Until now, there still doesn't get the full record about the microbial activity to glass corrosion phenomenon. Only a few related researches in the glass surface growth of microorganisms are published (Marvasi *et al*., 2009). Actually, this kind of phenomenon, the slightly degradation can be able to observed, such as the aquarium glass walls, fat, dust, moisture and volatile component can lead to the adsorption and growth of the microbe and glass surface will be corroded gradually and thus make glass surface eventually appears close to the frosted glass (Krumbein and Gorbushina, 2009).

In the early days of observation, some researchers have noticed that the oligotrophic microbes can live on the surface of seemingly no nutrition liquid and solid such as metal and glass, etc. (Wainwright *et al*., 1993), in the same historical building, the pitting corrosion structure of glass microbial corrosion, grain and metabolites are very similar with marble and limestone samples (Garcia-Valles *et al*., 2003; Krumbein *et al*., 1991).

Koestler *et al.* (1987) found that only on the glass surface of rich sodium, the breeding of microorganism is influenced by the humidity, the greater the humidity is the microbial degradation phenomenon is more serious; while the rich potassium glass in low humidity conditions (caused by microbial reproduction) of flaking and fracture phenomenon does not appear in high humidity conditions. Garcia-Valles *et al.* (2003) made the related research on several churches in the Mediterranean climate environment, the studies show that degradation of glass the surface of which have rich potassium and calcium are in two forms, i.e., the dissolution (the pitting in microscopic and mesoscopic) and its structural (product of which is green rust and crusting), at the same time the thickness of glass main body will become thinner.

In the corrosion process of stained glass windows, in the past, it is often attributed to the chemical corrosion effect. At present, Valentin *et al.* (1996) studied the Spain's cultural relics of the stained glass windows and the related results of experiments show that under the condition of appropriate relative humidity, the dust on the surface of the glass and the condensate can lead to the development of microbial species and lead the degradation of glass. In addition, Staudigel *et al.* (1995) studied the nuclear waste glass surface exposed to seawater, the related experiments also show that microorganisms in natural and synthetic glass play an important role in the process of dissolving and microbial degradation caused by glass is faster than most of the geological processes (geological the processes).

Therefore, microbial damage to the cultural relic architectural glass phenomenon does exist; professionals engaged in the work of modern architectural glass heritage protection should be paid great attention to microbial degradation.

MICROBIAL DEGRADATION MECHANISM OF CULTURAL RELIC ARCHITECTURAL GLASS

Microbial degradation form of cultural relic building: Through the research analysis, Koestler *et al.* (1987) found that the glass surface of the microbial growth has three different consequences: Erosion surface or sub-surface directly, microbial adhesion phenomenon because mechanical damage and the microbial membrane fixed continued to soak the substrate surface.

Gorbushina and Palinska (1999) summarized many cultural relics and made the sample research of microbes on the architectural glass and found that the surface of the microbial metabolism is the reason of biomineralization deposition. And related results are that the fungi and algae (Cyanobacteria) cause pitting corrosion and crack; cells, hyphae and cytoplasm membrane (cellulose) filaments leaves scratches on the glass surface; the fungi or algae grows on a glass surface leads to the color change.

Microbial degradation cause of architectural glass of cultural relics: The understanding of microbial degradation of glass materials and its influence factors has important significance on cleaning and protection of cultural relics. Glass degradation mainly has three types, namely that the physical weathering, chemical corrosion and microbial degradation and air pollution caused by the modern industry and inappropriate cleaning measures also aggravate the deterioration process of the architectural in glass cultural relics. Krumbein *et al.* (1991) made the observational study that glass degradation characteristics and patterns of the

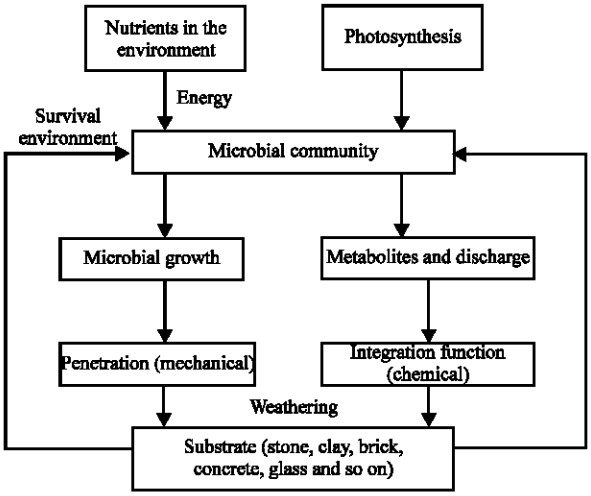

Fig. 1: Bio-degradation mechanism of glasses

induced by microbes and microbial pitting and one possible explanation is that the diffusion-finite decomposition (DLD clutches) fractal dimension.

Gorbushina and Palinska (1999) experimental evidences show that biomineralization deposition on the surface of glass is the metabolism of microorganisms (fungi and algae). In order to make the convenience understanding of architects and engineers working in the field of architectural heritage protection, non-metallic inorganic materials, such as glass, microbial degradation mechanism can be simply expressed in Fig. 1.

Recent comprehensive studies (Carmona *et al*., 2006; Muller *et al*., 2001; Gorbushina and Palinska, 1999; Drewello *et al*., 2000) it can be confirmed that the glass of the degradation can be attributed to chemical degradation process and the synergistic effect of microbial activity (synergistic effects). And in the process of the synergistic effect, the chemical composition of glass, which determine its durability or sensitivity to microbial corrosion, the composition of biological membrane (which presents the strain specificity) and the influence of climatic conditions in glass material and substrate surface growth of microorganism degradation are the three decision factors. Previous studies usually concern on the single microbe degradation effect and microbial degradation and the synergistic effect between the physical weathering, chemical corrosion is the research emphasis in the future.

Observation of microbial species: Glass surface morphology under normal conditions should be smooth or nearly smooth, except some tiny pit, there is heterogeneity of incrustation on the surface and often is full of white sediment.

In the early days, as the cultural relic architectural glass microbial degradation is not got enough attention and experiment conditions is limited, the researchers only can observe fungi and algae, but the lichen can not be directly identified (Krumbein *et al*., 1991) . In recent years due to the development of the surface analysis technique in the popularization and application in the study of microbial degradation, researchers have realized that microbial degradation bacteria on the surface of the glass is much more complex than previously research results (Rolleke *et al*., 1999). Schabereiter-Gurtner *et al*. (2001) found that cultural relics architecture glass is the habitat of fungi and bacteria, where has the high diversity of microbial consortium. The fungi and bacteria are mainly as below, Aspergillus (Aspergillus), short shank mildew genera (Aureobasidium), pear spore mould (Coniosporum), Capnobotryella (belong to have silk spore fungus), lateral teeth white mold (Engyodontium), ground wire mould (Geomyces), Kirschsteiniothelia phylum (belonging to the door plate capsule), ball cavity bacteria genera (Leptosphaeria), rosolic saccharomyces (Rhodotorula), Stanjemonium (belong to mitosis ascomycetes spores), Ustilago (Ustilago) and cyclic bacteria genera (Verticillium). However, the research of microbial community composition on glass surface where is dry environment and with poor nutrition is less (Muller *et al*., 2001).

Carmona *et al*. (2006) found the studied the glass samples of 15th century charterhouse (Cartuja DE Miraflores, burgos province, Spain) with external field emission scanning electron microscope examination and found a large number of round and hollow pit, as well as many micro cracks and fungal hyphae and conidium. Ecological niche hole detection, molecular recognition and conidium morphology have shown that the microbiologically induced corrosion of the glass main fungi is a. Tamari, also associated with other fungi and bacteria.

Marvasi *et al*. (2009) made the sample identification to Florence cathedral, built in the 13th century cultural relics architecture glass and study shown that the most representative bacterium is Bacillus genus Bacillus, Bacillus (Arthrobacter) and Bacillus (Paenibacillus).

The cultural relic architectural glass of microbial identification results show that the microbial proliferation affect on glass substrate degradation.

Summary: Above all, the microbial degradation impact of cultural relic building glass is the falling of the transparency of the glass, decrease of thickness and color changes in stained glass and so on. The main form is the

its degradation is the microbial membrane directly covering, microbial metabolites and secretion of mineralized crusting, microbes to grow in the micro cracks in caused by mechanical damage and microbial metabolites and secretion of acid solution. Therefore, in the modern building, the actively research should be conducted and cleaning technology of glass window should be adopted and the research results should be popularized as soon as possible.

RESEARCH ON MICROBIAL DEGRADATION OF GLASS EXPERIMENT TECHNOLOGY

Traditional technology: The most important repair means of cultural heritage is to realize the material degradation caused by microbes with early recognition (Rolleke *et al*., 2000). Degradation mechanism and protection technology research results depends not only on the researcher's observation and thinking ability, but also restricted by experiment technology and equipment. The traditional bacterial culture in degradation microbial species identification and comparative test is a common method (Staudigel *et al*., 1995). But the most basic observation method is still through the optical microscope (Fekrsanati *et al*., 2001).

New molecular biology techniques: The thickness of Biofilm and microbial components information provide the necessary research basis for optimizing the window cleaning procedures and its protection strategy (Muller *et al*., 2001). The microbial corrosion is a very complicated process, it involves adsorption and breeding of microorganism, electrochemical corrosion process and interface chemical process and many other factors affect it, in order to obtain the microbial corrosion mechanism, the electrochemical method sometimes are need to used in combination with other surface analysis method, such as scanning electron microscopy, electron probe, find out the different detection methods of correlation between the results (Liao, 2003). Application of the emerging technologies of molecular biology, the microbial degradation mechanism research will have a great promoting to the related research.

In optical analysis method of spectral analysis technology, the researchers used the scanning electron microscope (SEM) (Koestler *et al*., 1987) and the scanning electron microscope, X-ray microanalysis (SEM, EDS) (Garcia-Valles *et al*., 2003) and field emission scanning electron microscope (FE-SEM, field emission scanning electron microscopy) (Carmona *et al*., 2006). In addition the nucleic acid dye (Muller *et al*., 2001). Confocal laser scanning microscope and X-ray diffraction technique (XRD) (Garcia-Valles *et al*., 2003) are also got a certain application in the field.

In the optical analysis method of spectral analysis technology, molecular probe techniques is mainly adopted, such as ordinary electron microprobe analysis and fluorescent tags rRNA target oligonucleotide probe technology (Muller *et al*., 2001).

In the study of microbial community composition, polymer chain reaction and degeneration gradient technique (PCR-DGGE) has been widely used (Carmona *et al*., 2006; Marvasi *et al*., 2009; Rolleke *et al*., 1999; Schabereiter-Gurtner *et al*., 2001).

The special issue should be noticed is that when taking microbial samples, all kinds of gel system should be used in cultural relics glass in order to reduce toxicity, physical and chemical degradation and the potential risk of cloured pattern layer breaking away from on the glass (Valentin *et al*., 1996).

CLEANING METHOD OF CULTURAL RELIC ARCHITECTURE GLASS

Traditional method: The most meticulous work of uncovering original appearance of the relics is to clean these scale due to microbial degradation and the chemical and physical erosion and fouling. Over the past centuries, the mechanical removal has certain damage function and the chemical cleaning methods are adopted in the cleaning of the stained-glass windows. Today's cleaning process should have two complementary objectives: One is to improve the readability of the cultural relics of the glass and slow down the weathering process and the second is the removal of corrosion fouling should not endanger its artistic value at the same time.

According to this standard, the application of mechanical cleaning and improved methods of cleaning solution or gel pad, has obvious shortages (Murcia-Mascaros *et al*., 2008).

New cleaning technology: In the 2000, Drewello *et al*. (2000) developted the use of excimer laser radiation eroded relics biofilm on the glass. As known that the chemical stability of lower glass will promote the growth of high density biofilm, which only can use cleaning ways of high energy and high chemical stability of glass only allows the diffusion of a two-dimensional plane of biofilm on the glass surface, thus it can be remove with low energy density gently.

Drewello etc. found that decisive factor of the laser ablation effect on biofilm is the composition of the biofilm and its accumulated moisture and the ability to

manufacture glass degradation metabolites and formation of the corrosion potential. Almost at the same time, Fekrsanati *et al*. (2001) also made the comparative study of removal effect of different wavelength laser on microorganism of the glass surface. But the actual cleaning construction glass fouling with laser technology is different from the test work in the laboratory; equipment operational ability and its cost efficiency of factors limit the further popularization and application of such technology.

In addition, Murcia-Mascaros *et al*. (2008) proposed the method of dissolving calcium carbonate from the glass shell and the optimization of sulfate solution. The system is through the continuous on-line analysis of pH value, temperature and conductivity and calcium ion concentration parameters, to monitor and control the whole cleaning process. The technical scheme has the problem of high cost and difficult to promote application.

CONCLUSION

The recent research shows that almost all of glass material commonly used can occur microbial corrosion. At present, although the microbial degradation of glass materials has a preliminary understanding, but the research work of variety synergistic effect of degradation in the field are needed in its further promoting.

Inheritance and protection of the modern architectural heritage is our historical responsibility of each architects, engineers and related technical researchers. Domestic researchers of China should carry out targeted degradation mechanism analysis and study the cleaning and maintenance measures according to different climate condition, the condition of air pollution and characteristics of cultural relic building; with the guarantee of maintaining the light quality and art display effect of art glass, the developing of easy operation, moderate cost, no pollution and low contamination and reliable effect of cleaning technology is very necessary. Even it can draw lessons from nanotechnology and glass coated/coating technology and develop new research areas of the active glass degradation protection .

In addition, as the architectural glass degradation in cultural relic is a long-term, slow and imperceptible process, the degradation test of prevention measures and repairing technique research are difficult to get reliable conclusion in short time. Therefore, accelerated experiment method of researching glass material degradation is very necessary, which can verify results of the study for us in the shortest possible period.

ACKNOWLEDGMENT

This study is supported by National Natural Science Foundation of China (50778123/51178016).

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