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## **Detrimental effect of Air pollution, Corrosion on Building Materials and Historical Structures**

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**Abstract:** - The economy of any country would be drastically changed if there were no corrosion. The annual cost of corrosion world wise is over 3 % of the worlds GDP. As per the sources available, India losses \$ 45 billion every year on account of corrosion of infrastructure, Industrial machinery and other historical heritage. Keeping this critical and alarming situation in view, this paper focuses on how all these forms of corrosion affect building materials and historical structures. It also tries to bring awareness among the stakeholders of the environment and national heritage. The process of corrosion may be initiated in the form of chemical corrosion and electrochemical corrosion. The chemical may be witnessed in the form of direct oxidation, corrosion by liquid metals, fused halides and non aqueous solutions. Electrochemical corrosion may be seen in the form of immersion corrosion, underground corrosion and atmospheric corrosion.

**Keywords:** - Air pollution, Corrosion, Historical monuments, electrochemical corrosion, Oxidation.

### **I. INTRODUCTION**

With the advent of industrial revolution degradation of buildings has been identified. Though there are many reasons for degradation the principal reason may be attributed to air pollution. The air pollution in the form of acid rain may be chiefly responsible. The pollutants that are principally responsible for acid rain are sulphur dioxide and nitrogen dioxides. These two are emitted from the combustion of fossils fuels like coal and oil. The rapid industrialization has encouraged the quantity of these emissions. The quantity of these emissions has enormously increased in industrialized countries like UK, USA, Germany, France, Japan etc. The information on materials damage due to air pollution is very scanty. However, the information on corrosive effects of acid precipitation on metals is available for a few cities. Due to high concentration of industrial discharges and salinity and humidity in the air, corrosion rates in Mumbai are reported to be 3 to 6 times higher than those in other similar coastal areas of the country.

### **II. MATERIALS AFFECTED**

In fact, all most all materials are affected by the deposition of acid, but the degree of damage or intensity may be varied. Some of them are more susceptible to the affect such are Carbon, Steel, Zinc, Nickel, Limestone, Marble, Paints and some plastics. Basically metallic materials are spoiled due to corrosion. Oxygen and moisture are the chief agents responsible for corrosion. Submerged structures like foundations and pipes will also be affected by acidified waters due to corrosion caused by acid attack.

#### **2.1. THE CHEMISTRY OF CORROSION**

Corrosion causing acids may attack the material both in wet and dry form. Some of the pollutants in the gaseous form may fall close to the source of emissions causing direct damage. Sulphur dioxide frequently falls as dry deposition within 30 km of its source. Wet deposition of acids occurs when the pollutants are released in to atmosphere. They react with water vapor present in clouds to form dilute acids. Sulphur dioxide, nitrogen dioxide, carbon dioxide are the most responsible pollutants causing damage to the material. The intensity of damage caused by sulphur dioxide is more compared to the other pollutants. In fact in the reaction of the materials with pollutants many variables take place. The atmospheric concentration may play a major role in the

deposition of pollutants on to the surface of materials. When the pollutants fall on to the surface of the material the intensity of reaction depends on the nature of the material and amount of moisture content present in when  $\text{SO}_2$  falls as dry deposition on the material, it is oxidized to sulphuric acid in the presence of moisture in the surface.

### III. AFFECT OF AIR POLLUTION ON MATERIALS

The damage due to air pollution on materials is really a serious concern since the service life of buildings is remarkably reduced. It is true that the intensity of manmade pollutants on building degradation is more than the impact of natural pollutants. Most importantly the affects of soiling, degradation, corrosion and erosion caused by  $\text{SO}_2$  are very much serious. The effect of air pollution on materials may be seen in terms of discoloration, material loss, structural failing and soiling. Both discoloration and structural failure due to air pollution on buildings may be insignificant and that may not involve huge costs. But the effect of corrosion due to acidic deposition costs a lot. Especially the effect of sulphur dioxide and nitrogen dioxide emissions is very much significant. The effect of calcium sulphate has been very significant and may be continued for fairly long time. When calcium carbonate dissolves in sulphuric acid leads to the formation of calcium sulphate. The calcium sulphate when it falls on stone breaks the surface of the building blocks.

### IV. MAJOR AIR POLLUTANTS – AFFECT

Air pollutants deteriorate by five ways such as abrasion, deposition and removal, direct chemical attack, indirect chemical attack and corrosion. Air pollution is directly responsible for economic losses in urban areas. The atmospheric deterioration of materials are caused due to moisture, temperature, sunlight, air movement and the position of the materials.

**TABLE1:** The effect of air pollution on materials

MATERIAL EFFECTED	RANGE OF SENSITIVITY
Brick	very low
Concrete	low
Mortar	moderate to high
sandstone, limestone, marble	high
Unalloyed steel	high
Stainless steel	very low
Nickel and nickel-plated steel	high
Zinc and galvanised steel	high
Aluminium	very low
Copper	low

#### 4.1. OXIDES OF NITROGEN

It is produced from burning of fossil fuels and is responsible for acid rain when it reacts with atmosphere. Acid rain causes tremendous impact on the surface of material.

**TABLE 2:**  $\text{NO}_2$  levels in Indian cities

CITY	RANGE OF AVG. CONC. (PPM)	RANGE OF MAX. CONC. (PPM)
Mumbai	0.008-0.13	0.013-0.05
Delhi	0.008-0.13	0.016-0.035
Kolkata	0.006-0.17	0.023-0.051
Kanpur	0.01-0.095	0.02-0.013

#### 4.2. OXIDES OF SULPHUR

It is a corrosive gas comes from chemical, paper industries when it reacts with atmosphere it causes acid rain. The most notorious pollutant responsible for metallic corrosion is sulphur dioxide, it has been reported that corrosion of hard metals such as steel begins at annual mean concentrations of 0.02 ppm. Sulphuric acid mist in the atmosphere causes deterioration of structural materials such as marble sculptures and buildings have suffered damage in the last 30 years as a result of increased  $\text{SO}_2$  content in the atmosphere.

**TABLE 3:** Sulphur Dioxide levels in Indian cities

CITY	SULPHUR DIOXIDE LEVEL ( $\mu\text{G}/\text{M}^3$ )
Mumbai	47
Kolkata	33

Delhi	41
Chennai	8
Hyderabad	5
Kanpur	16
Ahmedabad	11

#### 4.3. CORBON MONOXIDE

The combustion of fossil fuels results in the emission of a variety of pollutants into the atmosphere of which the major ones are Sox, NOx and CO. Particularly the main sources of CO in the urban air are smoke and exhaust fumes of many devices, burning coal., gas or oil. These pollutants come from a big impact on the structures exclusively located near by the factories from where they are emitted.

TABLE 4: Carbon Monoxide levels in urban areas

City	Max. 1 hour CO (ppm)
London	58
Chicago	46
Los Angles	43
New York	27
Kolkata	35

#### 4.4. PARTICULATE MATTER

Particulates such as soot, dust and fumes soil painted surfaces, fabrics and buildings, and because of their abrasive nature, particulates can cause damage to exposed surfaces when they are driven by wind at high velocities. Through their own corrosiveness or in the presence of SO<sub>2</sub> and moisture, they can accelerate the corrosion of steel, copper, zinc and other metals.

TABLE 5: Particulate matter levels in Indian cities

City	Particulate level ( $\mu\text{g}/\text{m}^3$ )
Mumbai	240
Kolkata	340
Delhi	601
Chennai	100
Hyderabad	146
Kanpur	543
Ahmedabad	306

#### 4.5. OZONE

Ozone is a very reactive substance. Much of the degradation of materials, such as fabrics and rubber, now attributed to weathering caused primarily by Ozone. Ozone present in two layers of atmosphere. The part of Ozone that is present in lower layer of atmosphere (Troposphere) is more dangerous than the part present in Stratosphere. The Ozone present in the Stratosphere prevents the fall of Ultra violet radiation on to the earth as it shows an adverse effect on structures.

#### 4.5. INDIAN AMBIENT AIR QUALITY STANDARDS

The Central Pollution Control Board in India has set up ambient air quality standards with regard to permissible concentration of the following pollutants:

TABLE 6: Indian Ambient air quality standards

POLLUTANT	INDUSTRIAL AREA ( $\mu\text{G}/\text{M}^3$ )	RESIDENTIAL AREA ( $\mu\text{G}/\text{M}^3$ )	SENSITIVE AREA ( $\mu\text{G}/\text{M}^3$ )
<b>Sulphur dioxide</b>			
Annual Avg.	80	60	15
24 hrs	120	80	30
<b>Oxides of Nitrogen as NO<sub>2</sub></b>			
Annual Avg.	80	60	15
24 hrs	120	80	30
<b>Suspended Particulate Matter (SPM)</b>			

Annual Avg.	360	140	70
24 hrs	500	200	100
<b>Carbon Monoxide</b>			
8 hrs	5000	2000	1000
1 hr	10000	4000	2000

## V. INTENSITY OF DAMAGE

Most of the research studies revealed the effect of acid deposition on modern structures is significantly less than the effect on ancient monuments. All most all heritage structures are built up with lime stone and calcareous stones which are most vulnerable to corrosion. Hence continuous renovation and retrofitting is a must to protect our heritage. The historic structures all around the world are affected by acid rain. Most of the studies for the long time focused on the effect of sulphur pollutants, later the interest was diverted to the effect of nitrogen residues on the structures. Many of the researchers carried out studies on sulphur and nitrogen pollutants individually, they found their intensity of damage on materials. But in the recent past they could identify the effect of ozone and its acidifying air pollutants: in fact the effect of acid deposition on material can be studies under two important heads

The Taj Mahal, one of the Seven Wonders of the World, and India's pride, greatest land mark is also being threatened from air and water pollution. The report submitted by National Environment Engineering Research Institute deliberately shows that the 17<sup>th</sup> century monument is being damaged by air and water pollution. This is being happened even after the remedial measures taken by the government. The Ministry of Environment, Government of India has conducted a survey to find out the facts of pollution on the historical tomb. The report has revealed that the pollution levels in terms of both air and water had rose to most significant and dangerous level ,as a result of revolutionary growth in industry, traffic and population. Illegal and irrational constructions are springing up around the Taj Mahal, the heavily polluted water of the river Yamuna also causing a serious damage to the monument. An air pollution control programme was launched in 1998 when it was found the monuments famous and peculiar white marble was seen to be turning yellow. The then president Bill Clinton made an interesting statement that pollution had done "what 350 years of wars, invasions and natural disasters have failed to do and begun to mar the magnificent walls of the Taj Mahal". A series of serious banning measures have been taken including avoiding running of vehicles 500 meters away from the structure and sophisticated devices are arranged to provide running count of air pollution. It was also noticed that the fluctuations in ground water table have been threatening the structure, the water in the river Yamuna is continuously polluted by the discharge of effluents. Many experts declared that the measurable Total Particulate Suspended Matter (TSPM), Respirable Suspended Particulate Matter (RSPM) and Oxides of sulphur and nitrogen are all posing huge threats to the ancient monumental structures. The blackening of surface of structures due to the formation of dust layer over a period of time. According to Suryanarayana Murthy, a conservation architect, the organic matter that settle on the structure along with the dust leads to moth formation due to rains.



FIGURE 1: Pollution turning Taj Mahal yellow

Charminar, one of the greatest monuments in India, is being threatened by air pollution. Charminar was in most polluted area the TSPM recorded in 2010 was 267.5 and in 2012 it was 287. Some of the other oldest structures like Jama Masjid, Mecca Masjid and Badshahi Ashoorkhana are all affected by dust particulates. Architects notice that high levels of the TSPM are the biggest threat to monuments. It was also identified by Murthy that the formation of the layer happens much faster on structures with a rough surface as in the case of

Mecca Masjid, compared to the structure with smooth and plastered surface like Charminar. It has also been identified that it may take about eight to twelve month for a layer of 1 mm to form over the surface of Charminar, but it happens faster on structures like Mecca Masjid where the rugged stone is exposed. Charminar is the most famous icon of Hyderabad, now it has been suffering from deadly effect of air pollution. It was identified that the minarets of the monuments have developed air cracks at some places. Moss and Lichen growth has been identified on the walls facing the mosque on the second floor and it was also noticed on the steps leading to the upper portions. It was decided by Archaeological Survey of India (ASI) to take up repair activities at a cost of Rs 10 lacks. In fact ASI is authorized to look after its maintenance and it was also planned to take up chemical wash of charminar.

According to the available sources it was believed that the air cracks formed might be the result of climatic change. The heavy rains that lashed the city recently were believed to form precipitated matters on the surface of the structure. The seepage of rain water and the dampness have also shown their impact on air cracks. Dr. Das, the Official of ASI said during 2001, one of the minarets had suffered damage, but ASI had initiated an immediate action and rectified the problem.

The ASI has also identified that the vibrations produced by relentless movement of vehicles around it. ASI started an awareness programme called Charminar Pedestrianisation Project, in concerned with this project, some of the traffic volume has been diverted.



FIGURE 2: Air cracks on Charminar



**FIGURE 3:** Pollution on Statue of Liberty**VI. CONCLUSION**

The present contribution showed a general description on the current state of some of the historical structures. As far as the pollution on materials is concerned the tropical climate with the presence of natural pollutants create conditions for deterioration of both metals and rocky materials. In fact the present situation of historical structures is at critical junction. It is necessary that the appropriate governments should initiate substantial measures to control the damage of structures. The awareness among the public is also important to stimulate the concerned authorities to initiate control and remedial measures. This paper tries to place the facts and bring awareness among the public and custodian authorities.

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