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Effect of simulated acidic rain concentrations on selected materials used in construction

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ABSTRACT

With the rise of industrialization, increasing acidity in natural water and soil has become a big problem and serious threat to all the components of natural environment. This acidity is associated with the emission, transport, and subsequent depositions of oxides of sulfur, nitrogen and other acid oxidation products. In recent years, several national and international reports are in relation with deterioration of buildings. The present paper was aimed to study the effects of simulated acid rain on the materials used in building construction in order to find actual effect of acid rain concentrations on the buildings. The 'Periodic soaking experiments' were carried out with four different pH concentrations of namely pH 3, pH 4, pH 5 and pH 6 for eight days. The building construction materials used in the present study were Marble, Granite, Limestone, Cement-concrete blocks, Bricks, and Iron rods. Physical changes in iron rods were recorded and photographed under scanning electron microscope (SEM) to observe changes when immersed in the simulated acid rain samples. All the materials showed considerable weight loss with physical changes including rusting and scaling in iron rods. From the present study we conclude that acid rain concentrations have damaging effect on Marble, Cement/concrete blocks, and Brick as well.

KEYWORDS

Acid rain;
Periodic soaking experiment;
Sulfuric acid;
pH;
Dissolution.

INTRODUCTION

Acid rain is one of the most serious environmental problems emerged due to air pollution. Acid rain is a broad term that describes several ways through which acid falls out from the atmosphere which includes acidic rain, fog, hail and snow meaning that it possesses elevated levels of hydrogen ions (low pH). Acid rain is a natural precipitation containing acidic substances that cause its pH values to fall below 5.6[1]. It can have harmful effects on plants, aquatic animals and infrastructure. Nitrogen and sulphur oxides are the major sources of atmospheric acidity; both are products of combustion, and both are converted in the atmosphere to strong acids, mainly nitric and sulphuric acids that acidify the rain water[2]. Acid rain is in fact cocktail of mainly H_2SO_4 and HNO_3 where the ratio of these two may vary depending up on the relative quantity of oxides of sulphur and nitrogen emitted[3]. Main sources of these oxides are coal fired power stations, smelters (producing SO2) and motor vehicle exhausts (producing NOx). Urban air pollution is a major environmental problem, mainly in the developing countries[4]. These oxides may react with other chemicals and produce corrosive substances that are washed out either in wet or dry form by rain as acid deposition. *Nitrogen oxides* are produced naturally by lightning strikes, other prominent sources of nitrogen oxide include internal combustion engines, thermal power stations and to a lesser extent pulp mills. *Sulfur dioxide* is primarily produced by automobile and vehicular exhausts and naturally by volcanic eruptions. The acid rain can cause paint to peel, corrosion of steel structures such as bridges, and erosion of stone statues as well as buildings[5]. On one side this kind of development makes our lives easier, but on the other hand it results into pollution by release of harmful substances into the environment. Burning of fossil fuels in industries and transport sector, industrialization and urbanization have led to increase in concentrations of gaseous and particulate pollutants in the atmosphere leading to air pollution[6]. Presently acid rain is considered as man's "Chemical War" on nature and refers to the deposition of acidic atmospheric pollutants on soil, vegetation and causes damage because of pollutants. Primary reactions involved in formation of acid rain are:

$SO + H_2O \longrightarrow H_2SO_4$

$N_2O + H_2O \longrightarrow 2HNO_3$

Scientists often refer to "acid deposition" as a more accurate term for acid rain and along with the wet deposition there are also dry depositions of acids, which can be transformed into salts in the soil and cause the same environmental damage, as do the wet deposits. Dry deposition generally occurs close to the point of emission while wet deposition, however, may occur thousands of kilometers away from the original source of emission. But with the increased use of tall stacks for power plants and industries, atmospheric emissions are being transported regionally and even globally[7]. Atmospheric acid deposition in form of rain, fog or snow was identified as major environmental problems for the countries in Europe, East Asia and North America. Acid precipitation with pH values below 5.0 was registered in different regions of the world including Canada, England, Scotland, Sweden, Norway, Denmark, West Germany, Netherland, Austria, Switzerland, Brazil, Russia, Poland and Czechoslovakia, Southwest China, India and Japan[8]. Acid rain affects the quality of human life, threatens the environmental stability and the sustainability of food and timber reserves, thus posing an economic crisis. In recent decades acid deposition and the role of acidic air pollutants has become the cause of considerable concern at both national and international levels. This concern has centred mainly around adverse environmental and health effects, but also on damage to historical monuments.

Acid rain has also been reported in India. A rainfall of pH 3.5 was reported in Mumbai[9]. The air pollution levels are steadily rising in the metropolitan cities like Kolkata, Delhi, Mumbai, Korba[10]. The mean pH value of rain water was 9.1 during 1963 and 6.2 during 1984 at Delhi[11]. The world Meteorological organization has predicted substantial increase in acidity in cities like Hyderabad, Chennai, Pune and Kanpur[12]. In Singrauli region of Sonbhadra district in India, the acid depositions were found to be higher near the thermal power plant stations as compared to distantly situated site. The rainfall having pH 5.0 and 4.8 was reported towards the end of monsoon season at two sites close to thermal power stations[13]. Acid rain problem in Bihar, West Bengal, Orissa and southern coastal India has been predicted to lead to infertile soil. It is a substantial problem in China, Eastern Europe, Russia and areas down-wind from them, these areas all burn sulfur-containing coal to generate heat and electricity.

Following TABLES shows rainwater pH values in different regions of world and India.

TABLE 1 : Rain water pH values in different regions of world (modified from Khemani et al., 1994)

Countries	Range of pH
Japan	4.7
Europe	4.1 - 5.4
China acid rain area	4.1 - 4.9
China non - acid rain affected area	4.1 - 4.9
US north west	6.3 - 6.7
US west- middle-west	5.0 - 5.5
US north west	4.1 - 4.2

Effect of acid rain on buildings

The impact of acid deposition on buildings and structures of marble and limestone and on building materials containing large amounts of carbonate has been recognized for over a century and many studies have addressed the effect of acid wet deposition on stone material of historic buildings and monuments[14-16]. High buildings made of concrete in urban areas may also be damaged due to exposure to cloud water with high acidity for a long time[17]. Acid precipitation with a pH level ranging between 3.0 and 5.0 will affect cement and concrete[18]. The mechanism of deterioration in cement-based materials and in lime mortar was also studied by[19]. The effect of dry deposition of the single pollution species, such as SO_2, HCl, NO & Nitorgen dioxide on the degradation of calcareous building stones has been determined by Haneef et al.[20],

TABLE 2 : Range of rainwater pH in different parts of India measured at Bapmon station (modified from Datar et al., 1996)

Stations	pH
Allahabad	6.93
Jodhpur	7.42
Kodaikanal	6.28
Mohanbari	5.98
Visakhapatnam	6.01
Nagpur	5.97
Port Blair	6.15
Pune	6.43
Srinagar	7.22
Minicoy	6.58

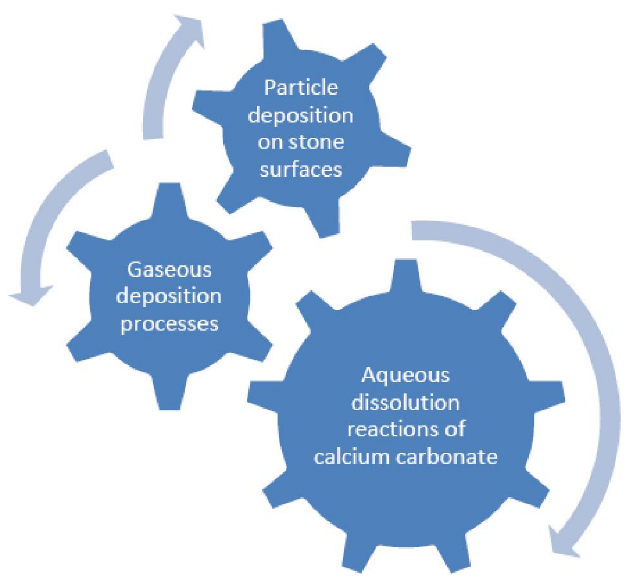

Figure 1 : Classes of mechanisms involved in air pollution and acid rain damage to buildings

Hutchinson et al.[21] and Johnson et al.[22] through laboratory tests. It has been found that acid rain causes chemical deterioration on carbonate stones and formation of soluble Ca^{2+}, HCO_3, SO_4^{2-} and that dry deposition of SOx, NOx on the surface of stones contributes to salt enrichment on carbonate stones and plays a major role in the deposition of acid substances on buildings[23]. The impact of acid deposition on the weathering of carbonate stone has long been recognized[24-26]. In recent decades acid deposition has become the cause of considerable concern at both national and international levels. This concern has centered mainly around adverse environmental and health effects and also on damage to historical monuments and buildings around us. It is known that three classes of mechanisms are involved in air pollution and acid rain damage to buildings[27] *and are shown in the following figure.*

Materials used in construction

(1) Marble is a non-foliated metamorphic rock which is widely used in construction and architecture.
(2) Granite is a common intrusive igneous rock. It is very hard and much stronger material than marble. It is commonly used in window sills of buildings.
(3) Limestone is a sedimentary rock composed of the minerals of calcite and different crystal forms of calcium carbonate. It is a widely used construction material and is also used in manufacture of cement.
(4) Cement is a binding material and is widely used in modern construction.
(5) Brick is a single unit or block of ceramic material. It is one of the most common and basic building construction materials.
(6) Iron rods are embedded inside cast concrete and are used to increase tensile strength of the concrete.

Case studies

The Taj Mahal, Agra, India: It has been observed that the color of Taj Mahal which has been constructed using white marble has turned to yellow in recent years. It has been estimated that acid rain or acidic precipitation has contributed to this change in color. On the front pillar on the right side of the Taj Mahal, slight damage is noted which is also said to be caused by acid rain. It is reported that the air in the place where the Taj Mahal is situated contains serious levels of sulfur and nitrogen oxides. This is due to the large number of power plants and industries set up around this area. All these factors lead to formation acid rain. This caused damage to this wonderful structure, which attracts many people from different parts of the world.

United States Capitol, Washington D.C., USA: The Capitol Building of the U.S. which has been constructed of limestone is also adversely affected by acidic precipitation. The resplendent U.S. Capitol Building's limestone is full of pockmarks from acid rain dissolving calcite. The damage is so severe in places that corners of limestone blocks that were once sharply wrought are now rounded.

EXPERIMENTAL

Materials

The materials used to check the effect of simulated acid rain concentrations were Marble, Granite, Limestone, Cement/concrete blocks, brick and Iron rods.

Figure 2 : Materials used in the experiment

Methodology

Experiment method

Periodic soaking experiment method was used in the present investigation[18]. In this experiment, all the building construction materials mentioned earlier were soaked in the simulated acid rain samples ranging from pH 3 to pH 6 for 8 days. The materials were daily taken out of simulated acid rain samples, wiped with a clean cloth and weighed on an electronic balance.

Preparation of simulated acid rain

The simulated acid rain samples were prepared by dissolving 30 ml of 1 N H_2SO_4 in 1000 ml of distilled water. This diluted sample showed pH of 1.9 which was added drop by drop to tap water (pH 7.01) to decrease it's pH to 3, 4, 5 and 6 which would pose as simulated acid rain. Various concentrations of acid rain samples were prepared because the pH of acid rain is not same everywhere, it significantly varies with the changes in pollution levels[28].

Pre-experimental procedure of the specimen

The marble, granite and limestone were cut using "marble bridge cutting machine", the bricks were cut by using axa parting blade, the cement blocks were compacted in plastic trays and the iron rods were cut using sledge hammer. All the materials except iron rods were exactly weighed to 100 g, the marble, granite, limestone and bricks were adjusted to the weight of 100 g by using sand paper. Iron rods were not weighed because only physical changes were to be observed.

Photography of iron rods used under scanning electron microscope (SEM)

The iron rods immersed in the simulated acid rain samples were photographed under Scanning Electron Microscope (SEM) and observations were recorded. A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. SEM can achieve resolution better than 1 nanometer.

RESULTS

From the results obtained (TABLE 3), it is clear that effect of simulated acid rain concentration of pH 3 was the most damaging in the view of decrease in weight of selected five materials used in construction. Maximum serial decrease on day to day basis was observed in limestone and remained with 11.3 g on 8^{th} day (total percent loss was 88.7) whereas, the lowest decrease in weight was observed in Granite and remained with 37.4 g on 8^{th} day (62.6 %) showing its strength and durability against simulated acid rain concentrations. Brick material also showed better ability to withstand the simulated acid rain concentrations. Marble and cement blocks also lost considerable amounts of weight as represented in Figure 3. The materials immersed in simulated acid rain concentration of pH 4 (TABLE 4) also showed significant weight loss due to dissolution mechanism. Limestone lost the maximum amount of weight in pH 4 also and its weight was recorded as 13.5 g on the 8^{th} day of the experiment (loss of 86.5%).

Granite lost the least amount of weight remained with 38.6 g on 8th day (loss of 61.4 %) proving to be the strongest and most durable construction material against acid rain. Marble lost a total of 80.5 % of weight followed by cement block which lost a total weight of 68.7 % where brick lost a total weight of 64.5 % on 8th day (Figure 4).

TABLE 3 : Decrease in the weight (g) of the specimens immersed in simulated acid rain of pH 3

	Marble	Granite	Limestone	Cement / Concrete	Brick
Start	100	100	100	100	100
Day 1	89.6 (±3.9) -10.4	92.1 (±2.61) -7.9	88.9 (±3.69) -11.1	91.3 (±2.89) -8.7	91.7 (±2.47) -8.3
Day 2	79.3 (±3.45) -20.7	84.3 (±2.62) -15.7	77.8 (±3.70) -22.2	82.6 (±2.90) -17.4	83.5 (±1.33) -16.5
Day 3	68.9 (±3.45) -31.1	76.5 (±2.63) -23.5	66.7 (±3.66) -33.3	73.9 (±2.92) -26.1	75.2 (±2.48) -24.8
Day 4	58.5 (±3.5) -41.5	68.7 (±2.64) -31.3	55.7 (±3.71) -44.3	65.2 (±2.93) -34.8	67.0 (±2.65) -33
Day 5	48.2 (±3.4) -51.8	60.9 (±2.65) -39.1	44.6 (±3.70) -55.4	56.6 (±2.96) -43.4	58.7 (±2.85) -41.3
Day 6	37.9 (±3.45) -62.1	53.0 (±2.70) -47	33.5 (±3.70) -66.5	47.9 (±2.90) -52.1	50.5 (±2.86) -49.5
Day 7	27.5 (±3.47) -72.5	45.2 (±2.76) -54.8	22.4 (±3.74) -77.6	39.2 (±2.94) -60.8	42.2 (±3.17) -57.8
Day 8	17.2 (±3.45) -82.8	37.4 (±2.79) -62.6	11.3 (±3.76) -88.7	30.5 (±2.95) -69.5	34.0 (±3.10) -66

Values are mean of three determinations; ± indicates; standard Deviation; Values with negative sign indicates percent decrease

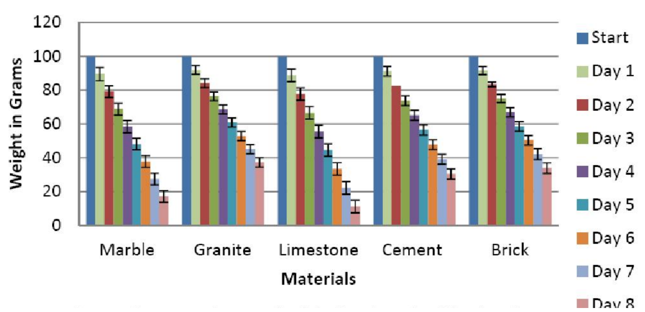

Figure 3 : Changes observed with simulated acid rain of pH 3

Effect of simulated acid rain samples on iron rods

It is observed that simulated acid rain concentration of pH 3 and 4 had more damaging capacity in terms of physical properties of the iron rods. There were moderate changes in physical appearance of iron rods immersed in simulated acid rain pH 5 while negligible changes were observed in iron rod immersed in simulated acid rain of pH 6.

TABLE 4 : Decrease in the weight (g) of the specimens immersed in simulated acid rain of pH 4

	Marble	Granite	Limestone	Cement / Concrete	Brick
Start	100	100	100	100	100
Day 1	90.5 (±3.15) -9.5	92.3 (±2.57) -7.7	89.2 (±3.60) -10.8	91.5 (±2.83) -8.5	91.9 (±2.70) -8.1
Day 2	80.8 (±3.25) -19.2	84.6 (±2.60) -15.4	78.4 (±3.60) -21.6	83.0 (±2.80) -17	83.8 (±2.70) -16.2
Day 3	70.5 (±3.66) -29.5	76.9 (±2.62) -23.1	67.6 (±3.62) -32.4	74.7 (±2.74) -25.3	75.5 (±2.80) -24.5
Day 4	60.8 (±3.81) -39.2	69.3 (±2.63) -30.7	56.8 (±3.63) -43.2	66.0 (±2.85) -34	67.5 (±2.75) -32.5
Day 5	49.7 (±4.60) -50.3	61.6 (±2.63) -38.4	46.2 (±3.50) -53.8	57.5 (±2.60) -42.5	59.7 (±2.60) -40.3
Day 6	39.6 (±3.30) -60.4	53.9 (±2.65) -46.1	35.2 (±3.50) -64.8	49.5 (±2.60) -50.5	51.4 (±2.70) -48.6
Day 7	29.5 (±3.65) -70.5	46.3 (±2.66) -53.7	24.4 (±3.51) -75.6	40.5 (±2.85) -59.5	43.5 (±2.60) -56.5
Day 8	19.5 (±3.90) -80.5	38.6 (±2.65) -61.4	13.5 (±3.51) -86.5	31.3 (±3.20) -68.7	35.5 (±2.55) -64.5

Values are mean of three determinations; ± indicates standard Deviation; Values with negative sign indicates percent decrease

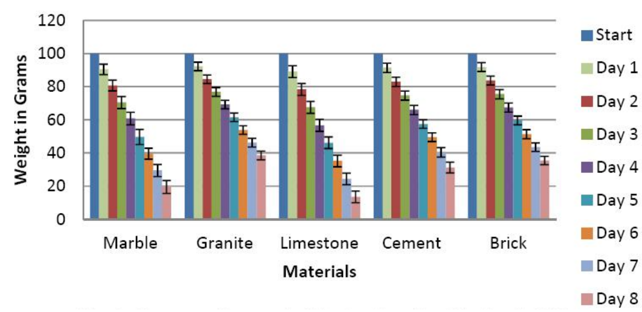

Figure 4 : Changes observed with simulated acid rain of pH 4

Scanning Electron Microscope images showed the clear cut adverse effect of simulated acid rain on iron rods. The iron rods before immersion in simulated acid rain samples didn't show any changes and are compact (Figure 8). The iron rods immersed in the simulated acid rain sample of pH 3 showed thick cracks (Figure 9) which proves that acid rain deteriorates the iron rods.

In the simulated acid rain concentration of pH 5 and pH 6 (TABLE 5 and 6), the construction materials showed weight loss but it was not as extreme as the weight loss observed in simulated acid rain concentration of pH 3 and pH 4 (TABLE 3 and 4). Limestone lost the maximum amount of weight in the simulated acid rain concentration of pH 5 and pH 6 which was recorded as 28.6 g (loss of 71.4 %) and 39.5 g (loss of

TABLE 5 : Decrease in the weight (g) of the specimens immersed in the simulated acid rain of pH 5

	Marble	Granite	Limestone	Cement / Concrete	Brick
Start	100	100	100	100	100
Day 1	91.5 (±2.85) -8.5	93.9 (±2.00) -6.1	91.1 (±2.97) -8.9	93.4 (±2.20) -6.6	93.7 (±2.10) -6.3
Day 2	83.1 (±2.90) -16.9	87.8 (±2.00) -12.2	82.2 (±2.95) -17.8	86.8 (±2.19) -13.2	87.4 (±2.15) -12.6
Day 3	74.7 (±2.80) -25.3	81.7 (±2.00) -18.3	73.5 (±2.85) -26.5	80.2 (±2.20) -19.8	81.5 (±1.09) -18.5
Day 4	66.2 (±2.90) -33.8	75.5 (±2.1) -24.5	64.4 (±3.00) -35.6	73.5 (±2.25) -26.5	74.9 (±2.05) -25.1
Day 5	57.8 (±2.91) -42.2	69.5 (±2.05) -30.5	55.7 (±2.90) -44.3	67.3 (±2.05) -32.7	68.5 (±2.10) -31.5
Day 6	49.4 (±3.05) -50.6	63.2 (±2.15) -36.8	48.5 (±2.10) -51.1	60.5 (±2.15) -39.5	62.2 (±2.10) -37.8
Day 7	40.9 (±2.95) -59.1	57.3 (±2.05) -42.7	37.2 (±3.25) -62.8	53.8 (±2.20) -46.2	54.3 (±2.90) -45.7
Day 8	32.5 (±2.95) -67.5	52.0 (±1.68) -48	28.6 (±3.10) -71.4	46.6 (±2.50) -53.4	49.2 (±2.30) -50.8

Values are mean of three determinations; ± indicates standard Deviation; Values with negative sign indicates percent decrease

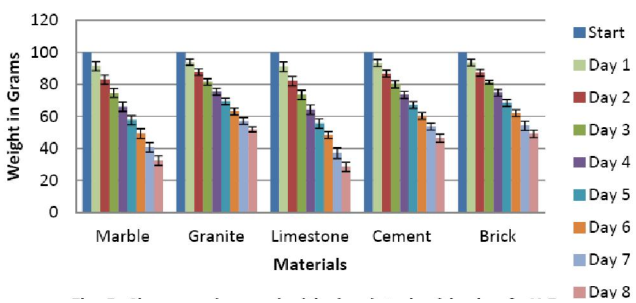

Figure 5 : Changes observed with simulated acid rain of pH 5

60.5 %) respectively. Granite proved to be the most durable construction material as it showed least decrease in weight at pH 5 and pH 6 where it lost only 48 % and 32.7 % of total weight respectively. In the acid rain concentration of pH 5 (TABLE 5), Marble lost a 67.5 % weight, cement block lost a total 53.4 % and Brick lost 50.8 % of weight (Figure 5). In the acid rain concentration of pH 6 (TABLE 6), Marble lost a total weight of 54.3 %, cement block lost a total by 39.9 % and brick lost a total weight by 35.5 % (Figure 6).

It was observed that the limestone lost most of the weight, that is, it dissolved the most, followed by marble. Cement blocks also lost considerable amount of weight whereas, the brick lost moderate amount of weight. Granite has proved to be the most durable construction material as it dissolved the least. Many physical changes like corrosion, scaling, and appearance change were observed in iron rods. For further observations, the iron rods were photographed under Scanning Electron Microscope (SEM), which clearly show the adverse effects of simulated acid rain on the iron rods and prove that acid rain corrodes metals. The weight loss of construction materials directly indicate towards the deteriorating or adverse effects of simulated acid rain on the construction materials but along with this considerable loss in weight of the materials, the demonstrated construction materials underwent some physical changes like the iron rods showed. These changes were easily observed with naked eyes. The marble specimens which were immersed in simulated acid rain of pH 3 and pH 4 showed slight yellow coloration. The cement/concrete specimens immersed in simulated acid rain of pH 3 and pH 4 lost their hardness slightly became soft and developed thin cracks. The red bricks used also developed thin cracks and in the simulated acid rain of pH 3, pH 4

TABLE 6 : Decrease in the weight (g) of the specimens immersed in the simulated acid rain of pH 6

	Marble	Granite	Limestone	Cement / Concrete	Brick
Start	100	100	100	100	100
Day 1	93.3 (±2.20) -6.7	95.9 (±1.35) -4.1	92.5 (±2.50) -7.5	95.1 (±1.60) -4.9	95.9 (±1.30) -4.1
Day 2	86.7 (±2.19) -13.3	91.8 (±1.36) -8.2	85.1 (±2.45) -14.9	90.5 (±1.45) -9.5	91.2 (±1.45) -8.8
Day 3	79.5 (±2.40) -20.5	87.5 (±1.45) -12.5	77.4 (±2.55) -22.6	85.3 (±1.60) -14.7	86.7 (±1.50) -13.3
Day 4	73.2 (±2.25) -26.8	83.6 (±1.40) -16.4	70.0 (±2.50) -30	80.4 (±1.65) -19.6	82.5 (±1.45) -17.5
Day 5	66.5 (±2.25) -33.5	79.6 (±1.36) -20.4	62.5 (±2.50) -37.5	75.5 (±1.66) -24.5	78.1 (±1.46) -21.9
Day 6	59.8 (±2.25) -40.2	75.5 (±1.34) -24.5	55.4 (±2.30) -44.6	70.7 (±1.60) -29.3	73.7 (±1.45) -26.3
Day 7	51.1 (±3.30) -48.9	71.4 (±1.35) -28.6	47.5 (±2.50) -52.5	65.5 (±1.70) -34.5	69.2 (±1.50) -30.8
Day 8	45.7 (±2.61) -54.3	67.3 (±1.35) -32.7	39.5 (±2.75) -60.5	60.1 (±2.01) -39.9	64.5 (±1.65) -35.5

Values are mean of three determinations; ± indicates standard Deviation; Values with negative sign indicates percent decrease

and pH 5 the bricks lost their color slightly.

To sum up the present investigation, we found that acid rain has adverse and deteriorating effects on the buildings as all the building/construction materials showed considerable loss or decrease in weight in the period of eight days when they were soaked in simulated acid rain samples, even the iron rods showed numerous changes in their physical properties therefore, it would not be wrong to say that not only the environment and the natural components face the consequences of acid rain but even the buildings around us are adversely affected by acid rain.

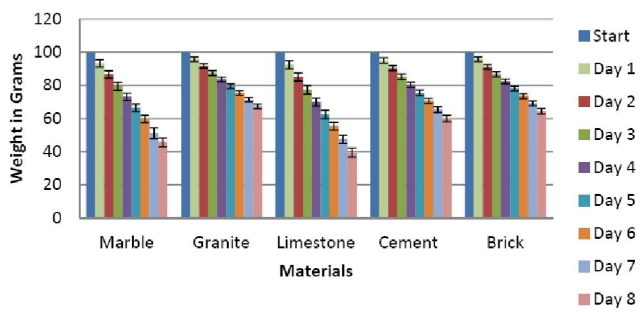

Figure 6 : Changes observed with simulated acid rain of pH 6

TABLE 7 : Physical changes observed due to simulated acid rain on iron rods

Properties/Effects	pH 3	pH 4	pH 5	pH 6
Corrosion	+++	+++	++	+
Color	+++	+++	++	++
Sample scaling	+++	++	+	+
Appearance change (luster)	++	++	+	+
Bubble formation	+++	+++	+	+

+ Very low or negligible effect, ++ Moderate/intermediate effect, +++ Very high effect.

DISCUSSION

The periodic soaking experiment has proved that there was corrosive effect of acid concentration the materials used in construction materials. It is well established that either wet or dry deposition of sulfur dioxide significantly increases the rate of corrosion on marble, granite, limestone and all other types of building material. It is observed that the limestone dissolved the most as compared to other materials used in this experiment. The dissolution of limestone can be represented by reaction- $CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2CO_3$[29]. The calcium sulfate formed is soluble in water and thus, limestone crumbles and dissolves. Though the simulated acid rain of different concentrations was used the observations were similar at all concentrations used. Limestone was the weakest construction material while granite proved to be the most durable and strongest material among all the materials used. It can be clearly observed that the weight reduction of the specimens decreases with an increase in the pH of simulated acid rain. There was considerable weight reduction of all the specimens of construction materials used in the experiment but the rate of weight reduction decreases with an increase in pH. Acid rain in various places around the world has its effect on the buildings with respect to its concentration which is directly proportional to the rate of emission and air pollution in the area[30].

The dissolution mechanism of construction materials in simulated acid rain concentrations was also identified by Leet and Judson[31]. They had demonstrated the mechanism of dissolution of limestone where and observed that acid rain is neutralized by calcium car-

Figure 7 : Iron rod in pH 3 (Left) and pH 6 (Right)

bonate and the pH. Our findings on five different construction materials are in accordance with the dissolution mechanism as well. In 1990, similar experiments were carried out by *Brookhaven National Laboratory (BNL)* which is a national laboratory of the United States of America. BNL also observed the dissolution of marble and we have obtained similar results to BNL if the dissolution of marble is considered[32]. Another study by United States Environment Protection Agency *(USEPA)* in April 2008[33] observed the effects of acid rain on building materials and monuments. They reported deteriorating effects of acid rain on the construction materials with the statement, "Acid rain eats away at stone, metal, paint and almost any material exposed to the weather for a long period of time. Human made materials gradually deteriorate even when exposed to unpolluted rain, but acid rain speeds up the process of deterioration and degradation".

On comparing our studies with that of Watkiss et. al[34] who observed the dissolution of concrete block slowly with the softening and development of cracks. We also observed the dissolving and softening mechanism and formation of cracks on the concrete block immersed in simulated acid rain. Potential impacts to concrete include soiling and discoloration and surface erosion.[35] Our results are also in good agreement with the interpretation of deteriorating mechanism of con-

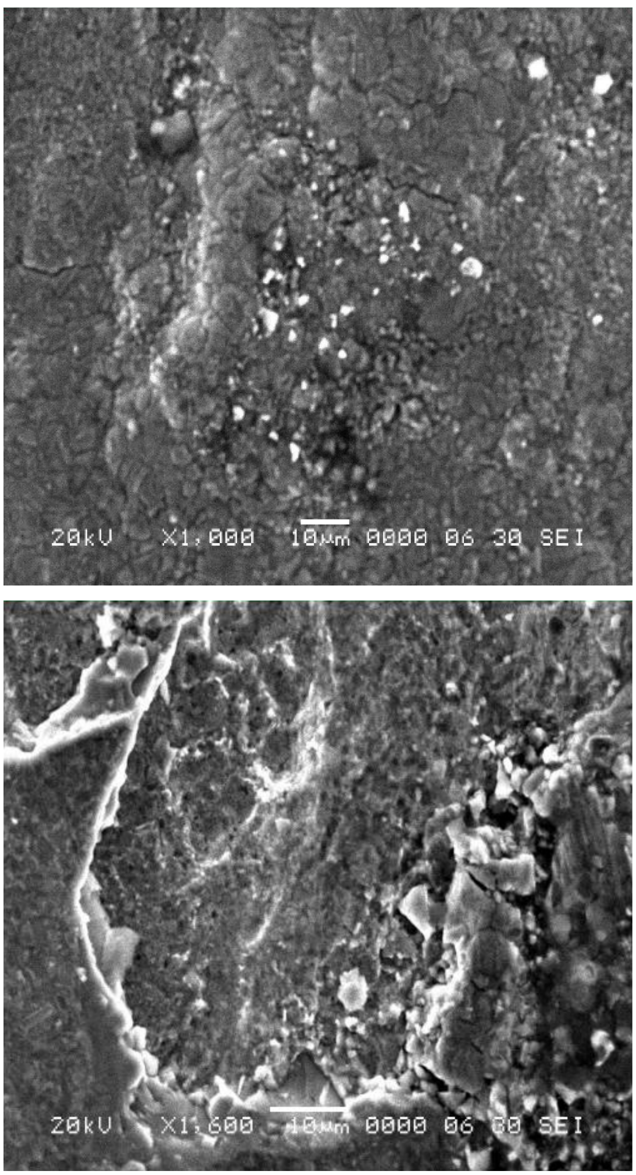

Figure 8 : Images of iron rod photographed under SEM before soaking them in the simulated acid rain samples.

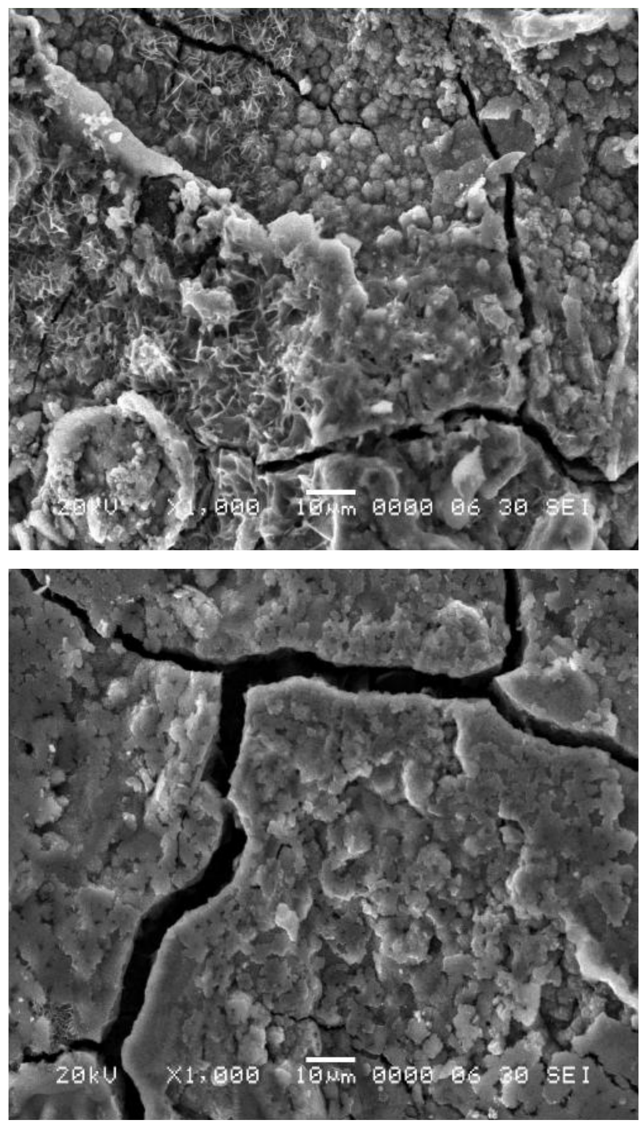

Figure 9 : Images of iron rod photographed under SEM after soaking them in the simulated acid rain sample of pH 3

crete in acid medium reported by other researches Marchand[36] and Metha[37]. The iron rods which were immersed in the simulated acid rain concentrations showed several changes in physical properties and when photographed under Scanning Electron Microscope (SEM). Thick cracks were observed on the iron rods which proves that acid rain also has deteriorating effect on metal. Acid rain speeds up the natural chemical weathering and corrosion of exposed materials in a variety of ways like ferrous metals are attacked by SO_2 and rusted more quickly. Steel building, railway tracts and other structures built of iron are very seriously affected by air pollution with extensive economic losses[38]. To sum up, the present study proved the adverse impact of acid precipitation on building materials. Acid rain not only affects buildings but also could considerably damage man-made structures like bridges, monuments and artworks made by using these materials.

CONCLUSIONS

Acid rain is a serious threat not only to plants and animals, but also to buildings, monuments, bridges and our very homes. The experimental results showed that there was considerable weight loss in the construction materials soaked in various concentrations of simulated acid rain. It is sufficient to prove that the acidic concentrations have damaging effect on the buildings around us. The hypothesis that limestone would see the greatest amount of damage from acid rain is proven to be true. The iron rods photographed under Scanning Electron Microscope (SEM) clearly showed the deteriorating effects of acid rain on metal. Considering all the facts, it is high time now, that every individual should try and minimize pollution which leads to acid rain. Following points highlight the conclusion of the experiment:

There was considerable weight loss in all the construction materials used in the periodic soaking experiment with deteriorating effects on Marble, Cement/concrete blocks, and Brick.

Limestone lost maximum amount of weight whereas, the least weight loss was observed in Granite proving to be the most durable and strong construction material.

The iron rods showed physical changes which can be clearly observed by SEM images.

Recommendations

As we all know that acid rain has adverse effects on plants, animals and all other living and non-living systems there is an urgent need of minimizing the impact of acid rain. In order to minimize the impact of acid rain, the basic step is control of air pollution; once we control the hazardous SOx and NOx emissions we can think of advanced measures to control acidic precipitation. In order to protect the buildings from acid rain and preserve old buildings which have historical value, we have to lay more emphasis on the development of new technologies and control measures to reduce and prevent air pollution. Abatement of air pollution and emission control are the most effective ways of reducing and minimizing the impacts of acid rain as these would directly prevent the formation of acid rain.

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