STM JOURNALS

International Journal of
Fracture Mechanics and Damage Science

Volume 2, Issue 2, 2024
July–December
DOI (Journal): 10.37591/IJFMDS

https://journals.stmjournals.com/ijfmds

Research IJFMDS

Study the Impact of Corrosive Pollutants on Building Materials Corrosion

Rajesh Kumar Singh[1,*], Pankaj Kumar Singh[2], Deepmala Kumari[3]

Abstract

Reinforced concrete structures (RCS) may be made more resistant to corrosion by using fiber reinforced polymers (FRP). One of the primary concerns with reinforced concrete constructions is corrosion. It causes disintegration in building material components by interactions with salts, acids, and alkalis. Both within and outside of reinforced properties, pollutants and effluents accelerate disbanding. When bio-waste and building materials come into contact, microorganisms and macro organisms, grow and emit acid compounds that hasten the corrosive process. Deformation of building block components is also caused by hostile agents such as acid rain, global warming, greenhouse gases, heat waves, climatic change, humidity, and moisture. Iron bars in reinforced concrete can corrode due to the prevalence of chloride ions in sea conditions. As the temperature of the atmosphere rises, the corrosion of building materials increase. Particulates make building materials particularly susceptible to corrosion. Chemical, biological, and electrical responses occur as a result of corrosive chemicals attacking the interface of reinforced frameworks and some of them entering through osmosis or diffusion methods. Such ambient conditions cause rebar steel to corrode in a range of ways, including galvanic, pitting, crevice, stress, intergranular, blistering, brittleness, erosion, and cavitations. It causes the concrete and rebar steel to collapse. Certain gases cause swelling and dissolving corrosion on the surface of concrete buildings by absorption moisture. The physical, chemical, and mechanical aspects of building block components are changed by corrosion techniques, which also detract from face features. Corrosion-resistant concrete is preserved by fiber-reinforced polymers. Developed countries spend 4% of their gross national product on corrosion preventative measures, part replacement, and upkeep. Mining, thermal power plants, refineries for oil and gas burning fossil fuels, chemical wastes, biological wastes, garbage from people, household wastes, agricultural wastes, animal wastes, food grain wastes, hospital trash, chimney flue gases, and industrial effluents are the main sources of corrosive substances. As effluents, these causes emit acids, alkalis, salts, organic compounds, metals, carbon oxides, nitrogen oxides, sulfur oxides, halogen oxides, sulfur hydride, nitrogen hydride, volatile organic molecules as flue gases, and other contaminants. Water, air, and soil are all contaminated by these toxic substances. Sand, stones, cements, iron bars, bricks, and water are the basic elements required for R C structures. The corrosive compounds specified above create an unfavorable environment for construction materials. This corrosive impact shortens the life of RC structures and causes internal as well as external disintegration, raising doubts about their stability, the lifespan, and durability. RC structures may be protected from corrosion using a variety of technologies. However, these methods did not provide them with sufficient safeguards. Therefore, fiber-reinforced polymers will be used as this effort to reduce RC structure corrosion.

Keywords: Building materials, Effluents, Pollutants, Flues gases, Wastes, Acid rain, Weather, R C structures and Fiber Reinforced Polymers.

***Author for Correspondence**
Rajesh Kumar Singh
E-mail: rks_jpujc@yahoo.co.in

[1]Associate Professor, Department of Chemistry, Jagdam College, J P University, Chapra, Bihar, India
[2]Research Scholar, Department of Chemistry, J.P. University, Chapra, Bihar, India
[3]Associate Professor, Department of Chemistry, Jagdam College, J.P. University, Chapra, Bihar, India.

Received Date: December 20, 2024
Accepted Date: January 15, 2025
Published Date: January 20, 2025

Citation: Rajesh Kumar Singh, Pankaj Kumar Singh, Deepmala Kumari. Study the Impact of Corrosive Pollutants on Building Materials Corrosion. International Journal of Fracture Mechanics and Damage Science. 2024; 2(2): 20–29p.

INTRODUCTION

External surfaces of concrete have been attacked by corrosive chemicals [1], which have a damaging impact. Contaminated cement, water, and ballast are

© STM Journals 2024. All Rights Reserved

the main causes of reactions of corrosion in concrete. Concrete is often mixed with natural water [2]. Before the cement hardens, a variety of chemicals undergo reaction with water. Corrosive environments are created by substances such as heavily contaminated streams and rivers, bog waters, and industrial effluents that may include polysaccharides or other organic compounds. Through an electrochemical process, chloride ions erode reinforcement. Pure water must be used in order for concrete to grow and develop. In the process of making cement [3], chalk, magnesia, and sulfate are applied with difficulty. External corrosive pathogens cause set concrete to corrode.

In general, water or aqueous solutions have an influence on chemical assault on concrete and mortar. Dust fragments and corrosive gasses can have a detrimental impact on mortar and concrete. These contaminants [4] penetrate the inside of mortar and concrete, starting a chemical manage that causes disbonding between them.

Cement, ballast, and reinforced steel comprise concrete [5]. In most cases, the ballast remains steady in the face of hostile media. On the other hand, gypsum can crystallize in the presence of sulphur and cause the concrete structure to break by swelling in ballasts that contain mica sheets, limestone, and some other ballasts that dissolve in waters that are acidic.

Although polymeric compounds are used to protect reinforced concrete structures against corrosion [6], they fail to operate well in corrosive environments. After infiltrating coated polymers and causing disbanding, corrosive pollutants eventually find their way throughout reinforced concrete, corroding building components, including rebar steel. When reinforced with fiber, corrosive pollutants' assaults decelerate down [7].

Experiment

The component of brick that is most vulnerable to assault comprises the cement. One of the most crucial building materials available today is Portland cement. It is created by intensely heating an amalgamation of clay and limestone. It is combined with a little amount of water and solidify into a product that resembles hard stone in a matter of hours. Chemically speaking, Portland cement [8] is a finely ground mixture of magnesium silicates and calcium aluminates of different compositions that hydrate when combined with water to create a solid, rigid structure with a substantial compressive strength [9]. The components listed in Table 1 are mixed separately to form Portland cement [10].

Table 1. Composition of Portland cement.

Formula	Abbreviation	Name
$2CaO.SiO_2$	C2S	Dicalcium silicate
$3CaO.SiO_2$	C3S	Tricalcium silicate
$3CaO.Al_2O_3$	C3A	Tricalcium aluminate
$4CaO.Al_2O_3.Fe_2O_3$	C4AF	Tetracalcium alumino ferrite
$CaSO_4.2H_2O$	Cs.2H	Gypsum

It is created by relations with water from the Portland cement clinker phase [11]. Tricalcium aluminate is a common reaction that delivers over 50% of Portland cement by weight. It displays the intricate procedure of cement hydration;

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \quad (1)$$

Calcium hydroxide, hydrated calcium silicate [12], and reaction byproducts from calcium aluminate (such as hydrated tetracalcium aluminate) and calcium aluminate ferrate make up the mixture. cement. Concrete is strengthened by hydrated calcium silicate in particular, but the alkaline characteristics of the set cement (PH > 12) is caused by calcium hydroxide [13].

Figure 1 illustrates the negative impact of several aggressive media on concrete. The products of hydration [14] behave uniquely against these media.

© STM Journals 2024. All Rights Reserved

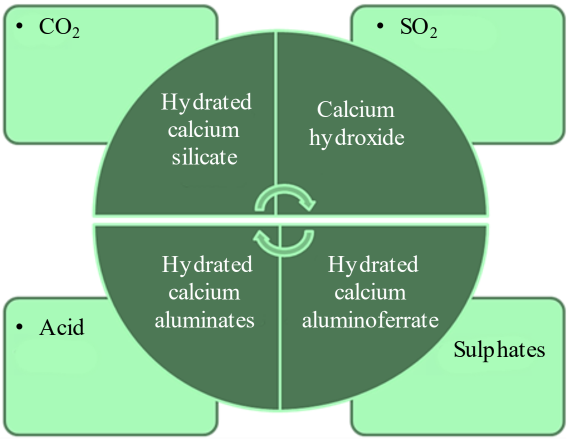

Figure 1. Corrosive substances attack on concrete.

Corrosion of Set Concrete: Figure 2 illustrates how various hostile substances, such as chemically pure water, inorganic and organic acids, alkalis, animals and plant oils and fats, mineral oils, coal tar distillates, and solutions of water, interact to erode set concrete [15]. When these cold materials [16] come into contact with cured concrete, a chemical reaction occurs and harm to the material occurs.

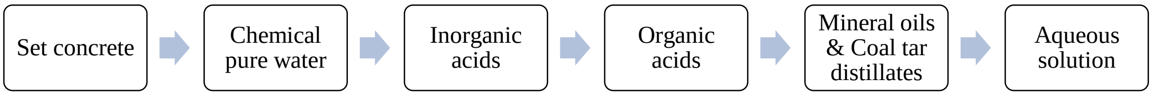

Figure 2. Set cement corroding substances.

Table 2 describes the many categories of corrosive materials [17] and also shows how they corrode. Table 2's findings show that minimizing corrosion in RCS is a difficult operation. However, FRP [18] coatings provide RCS with good results.

Table 2. Action of Corrosive Materials on Set Concrete

S.N.	Material	Occurrence	Action
1	Chemical pure water	Water of condensation rainwater, molten snow soft spring water	Dissolves, leaches out active in practice
2	Inorganic acids: (HCl, H_2SO_4, H_2SO_3, HNO_3 H_2SO_3, HNO_3 H_3PO_4, H_2SiO_4, H_2CO_3)	Chemical industry carbonic and sulphrous acids, natural waters	Dissolves, the stronger the acid the more intensely corrosive it is. Increasing activity is also found with falling pH value. H_2SO_4 Swelling effect. Carbonic acid corrosion Depends upon free CO_2.
3	Organic acids (acetic acid, lactic Acid, tannic acid, Formic acid, Oxalic acid) Humic acid Oxalic acid Alkalis (sodium & Potassium Hydroxides) Plants & animal oils and fats	During fermentation in dairies, canneries, fodder silos, dye works In soils and impure Ballast Dyeworks, chemical Factories In the chemical industry food industry and food trade	Dissolves slowly can slow down setting process Can attack slowly, depending upon type of humic acid Nondestructive Dissolves only when highly concentrated Loosens the structure dissolves by reaction of the fatty acids with calcium salts to form soft calcium soaps. Turpentine has no destructive effect.
4	Mineral oils and Coal tar distillates	Engineering sheds, filling stations, refineries	As these materials are non-acidic, they are

© STM Journals 2024. All Rights Reserved

			Nondestructive. All low Viscosity oils penetrate Concrete and act as Lubricants between set Cement and ballast to lossen structure. Phenol and cresol slowly corrode concrete.
5	Aqueous solution Mg2+ NH_4^+ SO_4^2 pH <6.5 CO,CO_2 & H_2CO_3 Na^+, K^+, Ca^{2+} Al^{3+}, Si^{4+}, NO_3^-, PO_4^{3-} and SiO_3^{2-}	In natural and Industrial waters Agricultural undertakings Artificial fertilizer factories In natural and industry waters In natural and industry waters In natural water In natural and industrial waters	Softens Dissolves Swells Dissolves Dissolves Not Harmful

Acid Corrosion: Acid concentrations and activity [19] determine how corrosive compounds are. Nitric acid, sulfuric acid, and hydrochloric acid are the strong acids. All of the ingredients in set cement are broken down by these acids [20], producing silica gel, calcium, aluminum, and iron salts. Weak acids, such as carbon dioxide and a variety of organic acids, include lactic acid and humic acid, combine with calcium molecules and produce water-soluble salts. After extended exposure, several kinds of damage are found.

When organic molecules break down, hydrogen sulfide in order [21] is produced as wastewater. Weak acid is created when it dissolves in water [22]. It may be oxidized to form sulfur and acidity after being absorbed by the concrete's humidity [23]. The key variable in both situations is an acidic assaults.

Flue gases includes SO_2 gas. In the presence of moisture and by oxidization, it can be transformed into sulfuric acid. Acid is also mostly to blame for this.

While bog waters [25], paint and dyes, medicines, food processing and preserving businesses, fruit juice factories, breweries, and dairies all create acids, effluents may include high levels of acids [24].

[26] Limestone dissolve in carbonic acid. Its pH value is not a sufficient indicator of its assault potential. It happens in water. Its even minute amounts provide concrete a corrosive the surroundings. Lime may be dissolved from concrete by carbonic acid, which functions analogous to other weak acids. Although lime stone is only partially soluble in water, adding a bit of carbon dioxide increases its solubility [27]. This corrosion is not impeded by the addition of dolomite.

$$\underset{\text{(Sparingly soluble)}}{CaCO_3} + H_2O + CO_2 \quad \underset{\text{(Very soluble)}}{Ca(HCO_3)_2} \qquad (2)$$

Salts' Ion Exchange Properties and The corrosion: The set cement reacts with magnesium chloride [28] and ammonium chloride, respectively [29] to produce magnesium carbonate, magnesium sulphate, nitrogen oxalate, and ammonium carbonate. The set cement contain calcium hydroxide [30], which combines with chloride to create compounds that degrade in water. Swelling may result from magnesium compounds separating as hydroxide, a soft, gel-like substance that either within or outside. A gas called ammonia [31] is generated.

© STM Journals 2024. All Rights Reserved

Soft Water Corrosion: There are fewer calcium and magnesium minerals in soft water [32]. Because of this, comparatively high amounts of these salts might get dissolved by water in concrete. Although the surface can be eroded by extremely soft water (less than 1.1 milliequivalent total hardness), well built sturdy concrete can withstand even very light water.

Fats and Oils Corrosion: Concrete is corroded by molecules of organic material [33] such as plant and animal fats and oils. Free fatty acids, which annihilate concrete like other weak acids, are present in varying amounts in all of them. Calcium salts (soaps) of the fatty acids and glycerol can be formed after the fatty acids react with the calcium compounds in the set concrete. Concrete breaks as a result of the fat's breakdown (saponification). Mineral oils [34] and fats don't damage concrete as long as they don't include any acids or resins. Concrete's durability and ability of adhesion to the steel reinforcement are affected if it is entirely impregnated with fats and oils. Generally speaking, swelling action is effective.

When sulphate [35] solutions seep into practical, chemical interactions between the calcium aluminate hydrates and various components of the set cement occur. Within the concrete, they create substantial new structures. The equation that follows stipulates:

$$3CaO.Al_2O_3 + 3(CaSO_4.2H_2O) + 26H_2O \quad 3CaO.Al_2O_3.3CaSO_4.32H_2O \tag{3}$$

The addition of a significant amount of water of crystallize results in the production of crystalline trisulphate, which has a volume significantly greater than the solid starting items. Because of the restricted amount of area it can occupy, it puts pressure on its surroundings, which causes cracking.

Cements with low trisulphate composition can prevent this sulphate expansion. Gypsum may separate from the calcium hydroxide solution in the cured concrete at very high sulphate quantities (1200 mg SO42-/litter). Swelling is another effect of this. Sulfate is mostly found in wastewater and soil.

RESULTS AND DISCUSSIONS

Fiber reinforced polymers for RCS Protection: Over time, different climatic variables show less of an impact on fiber-reinforced polymers than on other building substances. Weather fluctuations, such as changes in ambient temperature, air moisture in the form of fog, rain, snow, hail, and water vapor, air pollutants, ultraviolet radiation, wind, etc., do not have an immediate impact on the aging process. Chemical agents (such as oxygen and salt solution) and biological components (such as mechanical forces and static electricity) have no bearing. The use of FRP can help reduce other variable processes, such as chemical reactions which include oxidation, displacement, and double displacement reactions. Fiber-reinforced polymers prevent reinforced concrete structures from cracking by avoiding water absorption, evaporation, swelling, dissolution, precipitation, and all other processes entailed.

Fiber-reinforced polymers [36] offer color, brittleness, stability of surface structure, and chemical resistance. Special additives can be used to slow down the aging process. The additions, generally are referred to as stabilizers, light filters, and antioxidants, respectively, should stabilize the molecular structure, filter out UV and longer wave radiation, and lessen aging tendencies. Fiber-reinforced polymers have excellent weather resistance and can prolong the life of construction components. Fiber-reinforced resins such as polytetrafluorethylene (Teflon, etc.), phenolic and amino plastics, polyamides, polystyrene, polyethylene, and polyvinyl chloride exhibit good weather resistance and corrosion safeguarding against reinforced concrete [37].

These reinforced polymers and materials are not negatively impacted by the aging reactants. Table 3 lists several significant polymeric chemicals that can shield reinforced concrete from damage in environments that are alkaline or acidic.

© STM Journals 2024. All Rights Reserved

Table 3. Chemical resistance fiber reinforced polymers in acidic and alkali.

Polymers	Acids		Alkalis	
	weak	strong	weak	strong
Polyvinly Chloride(PVC)	effective	effective	effective	effective
Polyethylene(PE)	effective	effective	effective	effective
Polypropylene(PP)	effective	effective	effective	effective
Polyisobutylene(PIB)	effective	effective	effective	effective
Polystyrene(PS	effective	effective	effective	effective
PolymethylMethacrylate (PMMA)	effective	effective	effective	effective
Phenolic resins	effective	noneffective	effective	noneffective
Melamine formaldehyde	effective	noneffective	effective	noneffective
Urea Formaldehyde	effective	noneffective	effective	noneffective
Polyesterresins(UP)	effective	effective	effective	non effective
Polyamides(PA)	noneffective	noneffective	effective	noneffective
Polyurethane(PUR)	effective	noneffective	effective	effective
PolytetraFluoroethylene (PTFE)	effective	effective	effective	effective
Epoxy Resins(EP)	effective	effective	effective	effective
Polycarbonate(PC)	effective	effective	effective	effective

The polymeric polymers, which listed in Table 4 can prevent organic solvents from attacking reinforced concrete. The outsides of RC structures and shave foundation building materials are painted with these polymeric chemical compounds.

Table 4. The Chemical resistance of solvents important polymers.

Plastics	solvents		
	alcohols	***esters***	***ketones***
Polyvinly Chloride(PVC)	effective	noneffective	noneffective
Polyethylene(PE)	effective	effective	effective
Polypropylene(PP)	effective	effective	effective
Polyisobutylene(PIB)	effective	effective	effective
Polystyrene(PS)	effective	noneffective	effective
PolymethylMethacrylate (PMMA)	effective	noneffective	noneffective
Phenolic resins	effective	effective	effective
Melamine formaldehyde	effective	effective	effective
Urea Formaldehyde	effective	effective	effective
Polyester resins(UP)	effective	effective	effective
Polyamides(PA)	effective	effective	effective
Polyurethane(PUR)	noneffective	effective	effective
PolytetraFluoroethylene (PTFE)	effective	effective	effective
Epoxy Resins(EP)	effective	effective	effective
Polycarbonate(PC)	effective	noneffective	noneffective

In RC, fiber-reinforced polymers [38] are utilized to stop corrosion. The resilience of plastic protective coatings against a variety of hostile media is described by the structures shown in Tables 5 and 6. Rebar steel has been sealed by epoxy resins with polyamide hardener and chlorinated rubber. Pipelines that are to be buried in concrete have their ends wrapped around with polyethylenes [39]. Polyvinyl chloride is used to make acid-proof coatings and claddings. For instance, polytetrafluorethylene can be used to coat sheet steel and cover exterior buildings in marine weather climates because of its exceptional resistance to unfriendly media.

© STM Journals 2024. All Rights Reserved

Aluminum is coated with pu lacquer to make it resistant to weather and chemicals. In conjunction with the required building material, specific applications of fiber reinforced monomers for corrosion protection of building materials are frequently described. In the circumstance listed in Table 5, these fiber-reinforced polymers may successfully prevent corrosion in RC structures [40].

Table 5. The Chemical resistance of fuels important plastics.

Fiber Reinforced Polymers	Benzene	Gasoline	Mixture of fuels
Polyvinly Chloride(PVC)	noneffective	effective	effective
Polyethylene(PE)	noneffective	effective	noneffective
Polypropylene(PP)	effective	effective	effective
Polyisobutylene(PIB)	noneffective	effective	effective
Polystyrene(PS)	noneffective	effective	noneffective
Polymethyl Methacrylate (PMMA)	effective	effective	effective
Phenolic resins	effective	effective	effective
Melamine formaldehyde	effective	effective	effective
Urea Formaldehyde	effective	effective	effective
Polyester resins(UP)	effective	effective	noneffective
Polyamides(PA)	noneffective	effective	noneffective
Polyurethane(PUR)	effective	effective	effective
PolytetraFluoroethylene (PTFE)	effective	effective	Effective
EpoxyResins(EP)	effective	effective	effective
Polycarbonate(PC)	noneffective	effective	effective

The construction materials mentioned in Table 6 are corroded to certain minerals, plants, animals, oils, and fats. The employing of certain fiber-reinforced polymers can safeguard machining centers in this climate.

Table 6. The Chemical resistance of fuels important fiber reinforced polymers.

Fiber Reinforced	Mineral	Animal and plant	Oils and fats Polymers
Polyvinly Chloride(PVC)	noneffective	effective	effective
Polyethylene(PE)	noneffective	effective	noneffective
Polypropylene(PP)	effective	effective	effective
Polyisobutylene(PIB)	noneffective	effective	effective
Polystyrene(PS)	noneffective	effective	noneffective
PolymethylMethacrylate (PMMA)	effective	effective	effective
Phenolic resins	effective	effective	effective
Melamine formaldehyde	effective	effective	effective
Urea Formaldehyde	effective	effective	effective
Polyesterresins(UP)	effective	effective	effective
Polyamides(PA)	noneffective	effective	effective
Polyurethane(PUR)	effective	effective	effective
PolytetraFluoroethylene (PTFE)	effective	effective	effective
Epoxy Resins(EP)	effective	effective	effective
Polycarbonate(PC)	effective	effective	effective

Table 7 lists a few reinforced elastic compounds that prevent RC building components from corroding in the stipulated environment.

© STM Journals 2024. All Rights Reserved

Table 7. The chemical resistance of important elastomers

Elastomer	Mineral oil	Organic solvent	Water, acids, alkalis
Natural rubber	noneffective	noneffective	effective
Chlorinated rubber	effective	noneffective	effective
Polysulphide rubber	effective	effective	effective
Silicone rubber	effective	effective	noneffective
Polyurethane rubber	effective	effective	noneffective

CONCLUSION

Reinforced concrete buildings have been covered with fiber-reinforced polymers, which do create a link between them. Osmosis and diffusion, which are produced by many situations of danger, are reduced by these protective compounds. Building materials disbond as a result of these two processes, which allow corrosive contaminants to enter the concrete and start a corrosion reaction. For RC structures, the FRP coatings serve as reinforcement. However, because the surface of FRP has many porosities, which make it impossible to effectively regulate the osmosis and diffusion of pollutants, this form of coating does not produce satisfactory results over a prolonged amount of time. They are capable of corroding RCS and FRP. Applying a nanocoating on the surface of FRP to prevent osmosis and diffusion is the solution for the issue.

Acknowledgement

Author is thankful to UGC-New Delhi for providing Major Project and the title of Project is Study of Corrosion Protection of the Mahatma Gandhi Setu in Patna Bihar, India, F.No. 39-707/2010(SR). The author thanks other people who provided data collection and graph plotting.

REFERENCES

1. Condit, Carl W (1968) “Technology and Culture” The Reinforced-Concrete Sky Scrapers: The Ingalls Building in Cincinnati and its place in structural History.
2. Richard W. Steiger (1995) “History of concrete”. The Aberdeen Group.
3. W. Morgan (1995) “Reinforced concrete”. The Elements of structure. John F. Claydon (Civil Engineer)
4. Department of Civil Engineering (2015) “History of Concrete Building Construction:” University of Memphis.
5. Collins, Peter (1920-1981). Concrete: The Vision of a New Architecture. McGill-Queen’s University Press, pp-58-60.
6. Morsch, Email (1909). Concrete-steel Construction: (Der Eisenleltobaw). The Engineering News Publishing Compony, pp204-205.
7. Kim S, Surek J, J and J, Baker-Jarvis “Electromagnetic Metrology on concrete and corrosion” Journal of research of the National Institute of standards and Technology, Vol. 116;2011:655-69.
8. 8. Nilson, Darwin, Dolan of concrete structures, the McGraw-Hill Educatia, 2003:80-99.
9. “Effect of Zinc phosphate chemical conversion coating on corrosion behavior of Mild steel in alkaline medium: Protection of rebars in reinforced of concrete” Sci. Technol.Adv.Mater. 9:2008:04-09.
10. Birks, J. W., Calvert, J. G., & Sievers, R. E. (1993). The chemistry of the atmosphere: *Its impact on global change: Perspectives and recommendations*, pp. 170.
11. Brasseur, G. P., Orlando, J. J., & Tyndall, G. S. (1999). *Atmospheric chemistry and global change*. Oxford University Press, p. 654.
12. Davidson, O., & Metz, B. (2002). Co-chairs. Proceeding of workshop on Carbon Dioxide Capture and Storage p. 106. ECN.
13. Feely, R. A., Sabine, C. L., Hernandez-Ayon, J. M., Ianson, D., & Hales, B. (2008). Evidence for upwelling of corrosive “acidified” water onto the continental shelf. *Science*, 320(5882), 1490–1492. https://doi.org/10.1126/science.1155676’

© STM Journals 2024. All Rights Reserved

14. Finlayson-Pitts, B. J., & Pitts, J. N. (2000). *Chemistry of the upper and lower atmosphere*. Academic Press, p. 969.
15. IPPC (2001). Houghton J T, Ding Y, Johnson CA, Climate Change 2001, pp 881. New York: Cambridge University Press.
16. Lamaka, S. V., Zheludkevich, M. L., Yasakau, K. A., Serra, R., Poznyak, S. K., & Ferreira, M. G. S. (2007). Nanoporous titania interlayer as reservoir of corrosion inhibitors for coatings with self-healing ability. *Progress in Organic Coatings*, 58(2–3), 127–135. https://doi.org/10.1016/j.porgcoat.2006.08.029’
17. Manahan, S. E. (2000). *Fundamentals of environmental chemistry*. John Wiley & Sons, p. 268.
18. Maruthamuthu, S., & Muthukumar, N. (2008). Role of air microbes on atmospheric corrosion. *Current Science*, *94*, 359–363.
19. Melchers, R. E., & Li, C. Q. (2006). Phenomenological Modeling of Reinforcement corrosion in marine environments, A C Material [Journal], *103*, 25–32
20. Natesan, M., Venkatachari, G., & Palaniswamy, N. (2006). Kinetics of atmospheric corrosion of mild steel, zinc, galvanized iron and aluminium at 10 exposure stations in India. *Corrosion Science*, *48*(11), 3584–3608. https://doi.org/10.1016/j.corsci.2006.02.006
21. Ohtsu, M., &Tomoda, Y. (2007). Acoustic emission Techniques for rebar corrosion in reinforced concrete. *Advances in Construction Materials*, *7*, 615–622.
22. Prakas, D., & Singh, R. K. (2006). Protection of mild steel by thiourea derivative as inhibitors in 20% HCl. *Bulletin of Electrochemistry*, *22*, 257–261.
23. Prakash, D., &Singh, RK (2006) Protection of stainless steel in 20% HCl by use of organic inhibitors [Journal]. *Indian Chem. Soc.*, *83,* 1256–1259.
24. Prakash, D., & Singh, R. K. (2006). Corrosion inhibition of mild steel in 20% HCl by some organic compounds. *Indian Journal of Chemical Technology*, *13*, 555–560.
25. Quinet, M., Neveu, B., Moutarlier, V., Audebert, P., &Ricq, L. (2007). Corrosion protection of sol–gel coatings doped with an organic corrosion inhibitor: Chloranil. *Progress in Organic Coatings*, 58(1), 46–53. https://doi.org/10.1016/j.porgcoat.2006.11.007’
26. SHI Hong-wei (2009), Corrosion protection of AZ91D magnesium alloy with sol-gel coating containing 2-methly piperidine, Prog Org Coat, 66: 183-191.
27. Singh, R. K. (2007). Comparative study of mild steel and stainless steel inhibition in 20% HCl solution by some organic inhibitors. *Bulletin of Electrochemistry*, *23*, 113–117.
28. Singh, R. K. (2009a). Comparative study of the corrosion inhibition of mild steel and stainless steel by use of thiourea derivatives in 20% HCl,Solution. *Journal of Metallurgy and Materials Science*, *51*, 225–232.
29. Singh, R. K. (2009b). Corrosion protection of stainless steel in oil well recovery,*Material Science Research India*, *06*, 459–466.
30. Singh, R. K. (2010). The corrosion protection of stainless steel in phosphate Industry. *Journal of Metallurgy and Materials Science*, *52*, 173–180.
31. Singh, R. K. (2011). The corrosion protection of materials by nanotechnology, *Material Sci. Res. India*, *8*, 353–355.
32. Singh, R. K. (2015a). Corrosion control techniques for existing and new marine infrastructure, The Masterbuilder, *17*, 56–58.
33. Singh, R. K. (2015b). Building materials corrosion by fiber reinforced polymers, *Powder Metallurgy & Mining*, *1*, 1–5.
34. Singh, R. K., & Kumar, R. (2014). Study corrosion & corrosion protection of stainless in phosphate fertilizer industry. *American Journal of Mining and Metallurgy*, *2*, 27–31.
35. Singh, R. K., & Prakash, D. (2008). Inhibition of stainless steel by use of thiourea derivative as inhibitors in 20% HCl. *Journal of the Indian Chemical Society*, *85,* 643–646.
36. Singh, R. K., Thakur, M. K., & Latif, S. (2018). Corrosion protection of building materials in marine environment by nanocoating and filler techniques, *the Masterbuilder*, *20*, 68–76.
37. US EPA (2002). Greenhouse Gases and Global Warming Potential Values, Excerpt from the Inventory of US Greenhouse Emissions and Sinks : 1990-2000 pp 16.

© STM Journals 2024. All Rights Reserved

38. Vishwanadh, B., Balasubramaniam, R., Srivastava, D., & Dey, G. K. (2008). Effect of surface morphology on atmospheric corrosion behaviour of Fe-based metallic glass, Fe67Co18Si14. *Bulletin of Materials Science*, *31*(4), 693–698. https://doi.org/10.1007/s12034-008-0110-5
39. Wu, K. H., Chao, C. M., Yeh, T. F., & Chang, T. C. (2007). Thermal stability and corrosion resistance of polysiloxane coatings on 2024-T3 and 6061-T6 aluminum alloy. *Surface and Coatings Technology*, *201*(12), 5782–5788. https://doi.org/10.1016/j.surfcoat.2006.10.024
40. Xing-hua, G. U. O. (2009). Effect of sol composition on corrosion protection of SNAP film coated on magnesium alloy. *Chinese Journal of Inorganic Chemistry*, *25*(7), 1254–1261.

© STM Journals 2024. All Rights Reserved