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Experimental Investigation of Effect of Corrosion on Reinforced Concrete Beam

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***Abstract*:- Corrosion effect on reinforced concrete is one of major issue in construction industry. Reinforced concrete is widely used in construction industry due to its extensive accessibility. The outcome of steel corrosion includes damages cross section of steel area, cracks in concrete due to increasing expansive pressure, In coastal region due to effect of chloride deterioration of steel is cause which resulting into reinforcement corrosion which affects service and life of RCC structure. The bond strength between the steel reinforcing bar and concrete is thus reduced and the strength of the structure deteriorates. The objective of this study is to investigate the effect of corrosion on torsional strength, shear strength and flexural strength of reinforced concrete beams. We used accelerated corrosion technique to induced corrosion on reinforced concrete experimentally in laboratory. Using M20 grade with ordinary Portland cement, beam specimens are casted. Universal testing machine (UTM) is used flexural and shear strength and load and deflection behavior is analyzed. Specially prepared setup is used for torsional strength.**

Keywords*: *Accelerated corrosion technique, torsional strength, shear strength, flexural strength, load deflection

I. INTRODUCTION

Reinforced concrete (RC) is the foremost wide used building component due to its extensive accessibility. Reinforced materials are embedded within the concrete in such a way that the two materials resist the applied forces along. The concrete's compressive strength and steel's tensile strength form a strong bond to withstand these stresses over a prolonged span. Plain concrete is not appropriate for many constructions works, as a result of it cannot simply face up to the stresses generated by vibrations, wind, or alternative forces. Its utilized in completely different engineering applications worldwide like buildings, bridges, dams, and newly as a foundation system for wind turbine towers. RC structures are subject to a range of distinct ambient as well as marine, industrial and strengthened concrete applications, nuclear, and other extreme environments. Torsional strength is measure of ability of material to resist a twisting load. When the ultimate strength of the material is subjected to torsional loading, a material supports only the ultimate torsional stress before it breaks. In construction industry several structural components in building and bridges are subjected to vital torsional moments that have an effect on design. Examples of such components are spandrel beams in structures, beams in eccentrically charged multi-deck bridge frames, and box girder bridges. Shearing stresses which are calculated nearer to periphery are caused by torsional moments acting on cross section of beam. Generally, failures occurred by following factors: mistake in design calculation and flaw in detailing of reinforcement, blunder in construction practices, changing purpose of structure, wind and seismic action, depletion or drooping reinforcement steel area, it all happen because destructive attack of chloride ion resulting into causing corrosion. Corrosion is conversion of iron into its oxide and hydro-oxides in presence of oxygen and water. Passive film of calcium hydro-oxides around steel reinforced bar which basic in nature near PH around 12-13, That prevents corrosion. Carbonation of concrete i.e. chloride and CO_2 damages filmand CO_2 reacts with $CA(OH)_2$ it forms carbonates and bicarbonate of hydro-oxides with some amount of water, which reduces the PH. In this study effect of corrosion on torsional strength is studied on the basis of varying percentage of corrosion. The corrosion percentage is 0%,3%,6%,9%.

II LITERATURE REVIEW

The behaviour of RCC beams under corrosion has been studied by various researchers.

Shamsad Ahmad (2009): In this research paper author used induced accelerated corrosion technique. Accelerated corrosion technique is used because corrosion rate is very slow at normal condition. Reinforced beam takes long time for corrosion due to its protective nature of concrete. For doing research studies it is difficult to achieve significant percentage of reinforcement corrosion over duration available. Various method of reinforcement corrosion of steel bar in rc beam which is stated by author in this research paper.

Khaldoun Rahal (2011): In this research paper author invented simple method for predicting ultimate strength and mode of failure of reinforced concrete beam. This technique is based on a newly established technique for anticipating the strength of the membrane component that is subjected to pure shear and applied to bending moment beams, combined shearing force, axial loading.

Mohammad Rashidi, Hana Takhtfiroozeh(2016): In this research paper author is presented evolution of torsional strength of reinforced concrete beam. Motive of this experiment to find torsional strength subjected to transverse and longitudinal reinforcement. In this experiment four beam is used of same length and same concrete mix design. The aim of this experiment is to determine effect of reinforcementtype on torsional strength of concrete beam.

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A. Aryanto & Y. Shinohara(2012): In this research paper author stated that bond is one of important parameter toassess the performance of reinforced concrete structure. Author takes mainly seismic loading condition to check bond behavior, bond stresses, crack propagation, crack spacing under different level of corrosion of reinforcing steel. In this experiment seven number of cylindrical specimens of 19 mm bar diameter and
2.8 cover to bar diameter ratio were casted and tested under corrosive environment. The corrosion percentage varies from 0% to 4%.

Ahmed K El-Sayed, Raja R Hussain, Ahmed B Shuraim (2016): The authors administrated an experimental work on effect of corrosion of stirrups on shear strength of RCC beam. Only stirrups are subjected to corrosion before testing, main longitudinal bars are not subjected to corrosion.it is observed that shear capacity of beam is reduced.

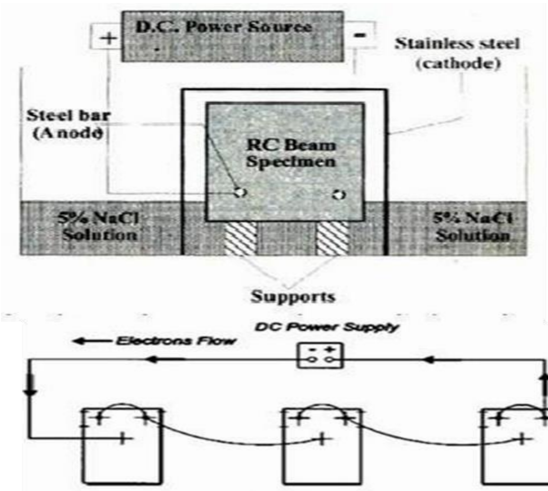
III OBJECTIVES

- To study effect of reinforcement corrosion on RC beam to determine torsional strength, shear strength, flexural strength of reinforced concrete beams.
- Develop a corrosion measurement device setup to calculate percentage of corrosion digitally.
- By using induced accelerated corrosion on steel (TMT) bars, determine effect of corrosion on reinforce concrete beam.
- Develop a test set up to carry out torsion-test on the RCC beam.

IV THEORETICAL CONTENTS

- **Accelerated Corrosion Technique:**

In this study the electrochemical corrosion method is used to induce accelerated corrosion in bars emended in concrete. To induce current in bars DC power supply of 48V and 4 amps is used. 5% concentrated NaCl is used as electrolyte solution. specimens are place in NaCl solution for a day to ensure fully saturated condition. Stainless steel bar is used as cathode and bars embedded in beam are used asanode.



Test set-up

Calculation of time for different percentage of corrosion

$$M_{th} = \frac{W\, I_{app}\, T}{F}$$

Where:
M_{th} = theoretical mass of rust per unit surface area of the bar (g/cm^2)
W = equivalent weight of steel (27.925 g) I_{app} = applied current density (Amp/cm2) T = duration of induced corrosion (sec)
F = Faraday's constant (96487 Amp-sec).

Time calculation for different percentage of corrosion

Percentage of Corrosion	Current (Amps)	Duration of Corrosion (Hours)
3	4	33.50
6	4	67
9	4	100.50

V METHODOLOGY

This study is experimental study to analyze behavior of RCC beams under the influence of corrosion. Concrete mix design is done according to IS10262 (2009). Concrete mix design is prepared to get M20 grade of concrete using OPC and water cement ratio of 0.5 is used.
Details of beam reinforcement: The beams designed as under-reinforced concrete beams and span of beam was 700 mm, width 150 mm, depth 150 mm.

- Top longitudinal main bars: 2 nos. 10 mm dia.
- Bottom longitudinal main bars: 2 nos. 10 mm dia.
- Stirrups: 2-legged 8 mm dia. stirrups at 110 mm C/C.

Casting of beams I done according to IS standards and 28 days curing of beams is done. All beams are kept for curing in same environmental condition. Corrosion of beams is done according to theory mentioned in theoretical content. Beams are tested in universal testing machine (UTM) for bending and shear capacity. Three-point bending test is used for bending and shear capacity. And specially prepared setup is used for torsional testing.

VI EXPERIMENTAL INVESTIGATION

After completing a mix design next step is casting of specimens. Cube and beams are casted using M20 grade concrete details of specimen are as follow:

SPECIMEN	SIZE (mm)	NO. OF SPECIMENS
CUBE	150 X 150	3
BEAM	150 X 150 X 700	24

The test specimen was an RC beam with a rectangular cross section, A specimen cross section was designed with a width of 150mm, an overall depth of 150mm, an effective depth of 125mm, two bars of 10mm diameter at top and two bars of 10mm diameter at bottom, 8mm diameter stirrups provided. The overall length of the beam was chosen as 700 mm with a 600 mm distance between supports. The stirrups had a clear cover of

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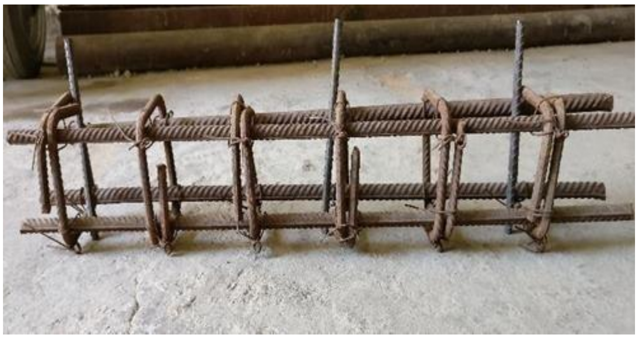
25 mm and a spacing s of 110mm. The specimens were tested under three-point bending. Concrete mixture proportion was cement: water: sand: gravel = 1:0.5:1.5:3

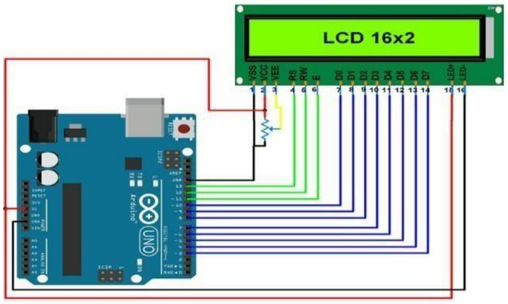


Accelerated Corrosion:
Equipment used for accelerated corrosion are voltmeter, ammeter, DC power supply etc.
After 28 days of curing of beams the test beams were put into 5% concentrated NaCl solution by weight of water in tank as shown in picture below. Depth of water in tank is kept constant throughout the corrosion process. Steel bars in beam are used as anode and stainless-steel bar immersed in water is act as cathode.

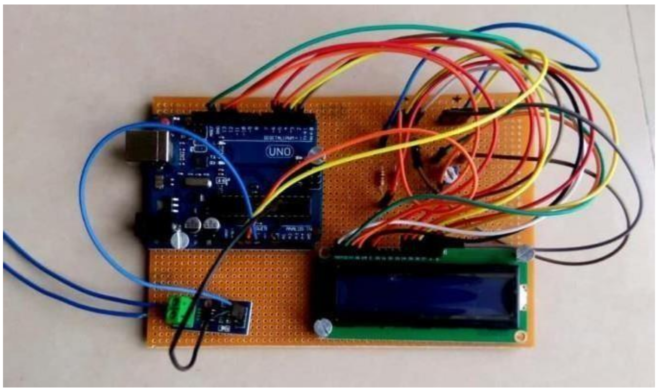
VII CORROSION MEASUREMENT:

Components-Arduino Uno, LCD (16*2), ACS 712 (Current sensor 5 amp), 10k pot, Resistor 560 Ω, Jumpers.

Methodology-The LCD is interfaced with the Arduino with respect to given diagram.



The 10k pot is used to control intensity of the LCD. The ACS 712 capable of sensing unidirectional as well as bidirectional current (AC/DC). There are various models capable of sensing 5A/20A/30A current. The module used in this research is capable of sensing 5A current. The current sensor yields voltage as output proportional to the change in current. This voltage is given to ADC of Arduino. The code for Arduino is written such that it displays on time of the circuit, current applied to circuit and percentage of corrosion (as per formula).



Circuit of Corrosion measurement

Advantages-

1. No need of external ammeter to measure current.
2. The percentage of corrosion is calculated automatically.
3. Completely digital device.
4. No need to keep track of "On Time" manually.

VIII RESULTS AND DISCUSSION

This chapter deals with the results obtained from the testing of the samples

Compressive test

Cubes were tested for compressive strength (fck). The results obtained are tabulated in Table as follow:
Compressive strength of cubes-

Samples	Failure Load (KN) Compressive	Compressive Strength of the Beam (N/mm2)	Mean Compressive Strength (N/mm2) Cube
Cube 1	530	23.56	
Cube 2	610	27.11	25.04
Cube 3	550	24.44	

Three Point Bending Test

Results of three-point bending test are tabulated in table given below:

Beam Specimen	Ultimate Load (KN)	Average Ultimate load (KN)	Deflection (mm)	Average Deflection (mm)
	101		10.5	
	93.19		10.7	
0%	100.1	98.12	9.55	10.25
	89.9		11	
	86.23		8.3	
3%	88.74	88.31	9.95	9.75
	78.48		8.25	
	78.48		10.75	
6%	80.442	79.13	8.6	9.2
	73.97	71.94	8.5	
	69.96		10.25	
9%	71.86		9.25	9.3

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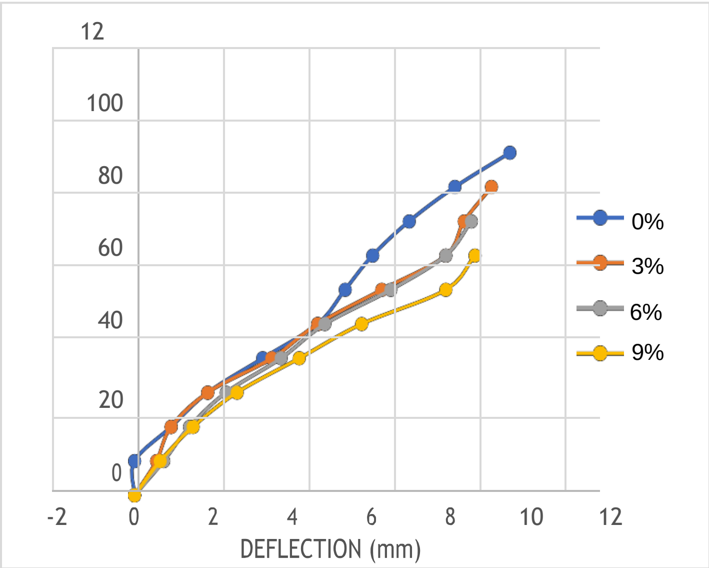
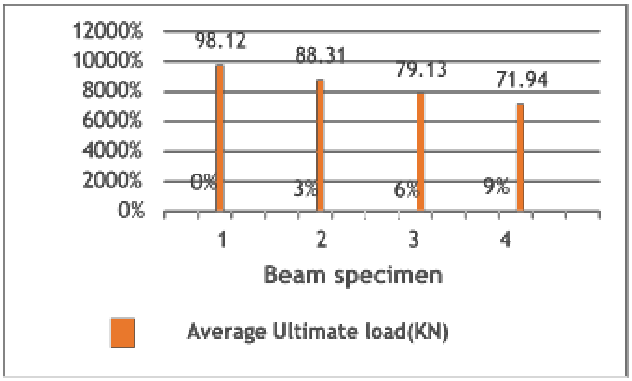
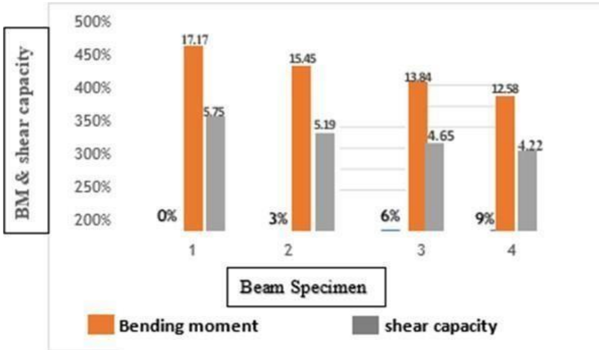
Load vs deflection for all specimens:





Bending Moment and Shear Capacity Of Beams

Beam specimen	Bending moment (KNm)	Shear force (KN)	shear capacity (KN)
0%	17.17	49.06	5.75
3%	15.45	44.16	5.19
6%	13.84	39.57	4.65
9%	12.58	35.97	4.22

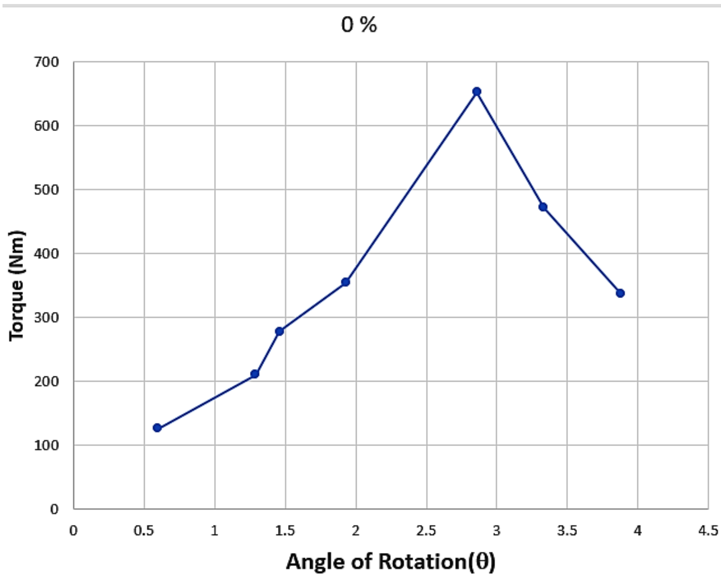


Torsion Test:

Results of torsion test are as given below:

<u>0% corrosion:</u>

Torque (Nm)	126.3	210.5	277.86	353.67	651.52	470.9	336.8
Angle of Rotation (θ)	0.6	1.29	1.46	1.93	2.86	3.33	3.88



Torsion v/s Angle of Rotation (0% corrosion)

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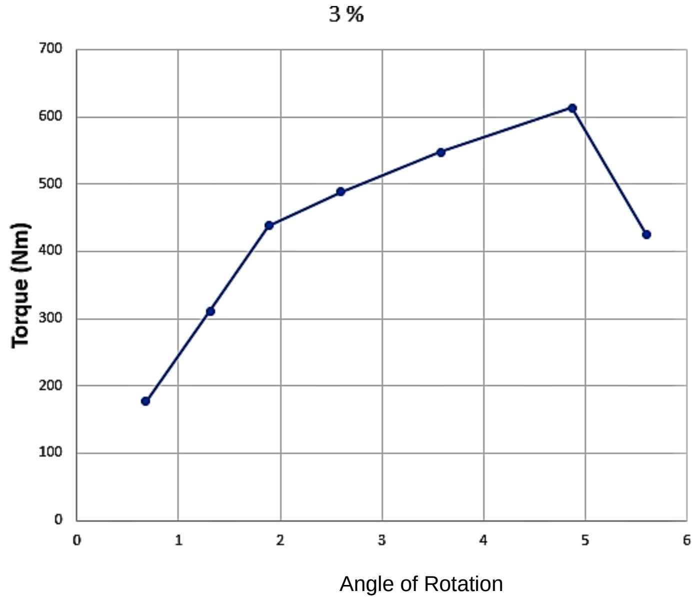
3 % corrosion:

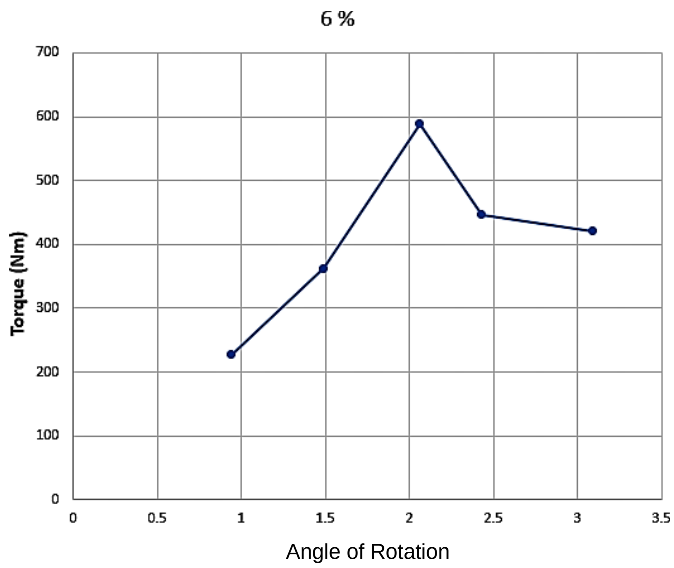
Torque (Nm)	**176.8**	**311.6**	**437.9**	**488.5**	**547.4**	**613.6**	**425.6**
Angle of Rotation (θ)	**0.68**	**1.31**	**1.89**	**2.6**	**3.58**	**4.87**	**5.6**



Torsion v/s Angle of Rotation (3% corrosion)

6 % corrosion:

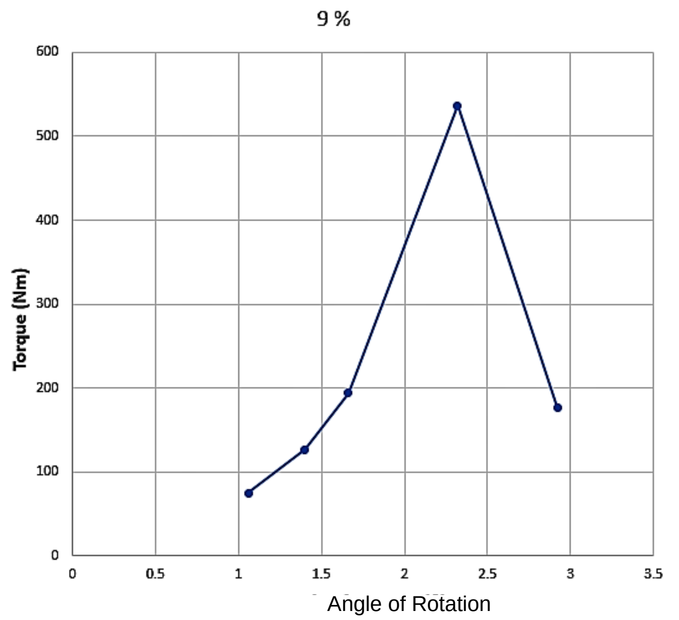
Torque (Nm)	227.2	362.2	588.6	446.27	421
Angle of Rotation(θ)	0.94	1.49	2.06	2.43	3.09



Torsion v/s Angle of Rotation (6% corrosion)

9 % corrosion:

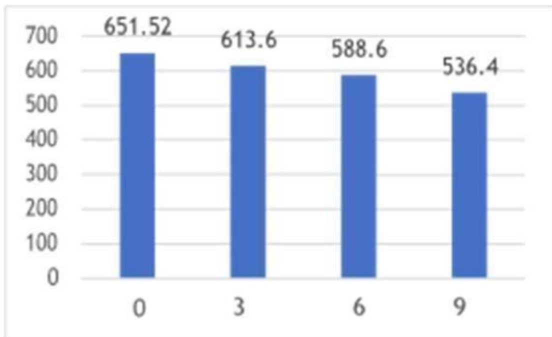
Torque (Nm)	74.5	126.3	193.7	536.4	176.8
Angle of Rotation (θ)	1.06	1.4	1.66	2.32	2.92



Torsion v/s Angle of Rotation (9% corrosion)

Effect of Corrosion On Maximum Torque:

Specimen	Max Torque (Nm)
0%	651.52
3%	613.6
6%	588.6
9%	536.4



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IX CONCLUSION

- From results obtained by experimental investigation it is observed that ultimate load carrying capacity of beam specimens is decreased by 26.18 % for 9% corrosion compared to controlled beam (i.e. 0% corrosion.)
- By experimental investigation it is observed that shear capacity of corroded beams and moment carrying capacity is less than that of controlled beam specimen.
- Crack width is less at lower level of corrosion (0% to 6%), after that is increasing rapidly (6% to 9%) Degradation in bond behavior is seen due to reinforcement corrosion.

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