

Evaluation of the Anti- Corrosive Coating on Railway Bogie Components

K.Velayutham, U.Arumugham, B.Kumaragurubaran, P.Gopal

Abstract— The objective of this project is to study the corrosion that occurs in Railway coach's bogie components, causes of corrosion, steps taken to prevent corrosion, suggestions to minimize this problem. This paper contains new suggestions to minimize the problems: more emphasis has been laid on Polytetrafluoroethylene (Teflon) coating to be suggested instead of black enamel or epoxy coating for bogie frame and bogie components of equalising rod and brake beam. The under mentioned components are the most affected parts due to corrosion near the bottom of lavatory. Another reason for bogie frame corrosion is easy peeling off coating surfaces due to scratch or dent marks produced by striking of ballast when trains are running.

The corrosion prevention behavior of commercially available epoxy coated surfaces and Teflon coated surfaces on structural steel were evaluated using various methods such as 3.5 wt. % NaCl solution salt spray test, 25% (v/v) sulphuric acid immersion test and loss of weight. Two different systems of coatings were selected for evaluation. The test panels same as of bogie component material composition were prepared and subjected to specific test as per experimental procedure. Optical microscope image were recorded on completion of corrosion test. We observed that after 504 hrs. exposure in atmospheric, Teflon coatings are still good in resisting abrasion and can withstand against corrosion more effective than other coatings.

Index Terms — Bogie components, Corrosion, Epoxy coating, Teflon coating.

I. INTRODUCTION

The annual loss for India, on account corrosion is around 75 crores rupees. Corrosion is phenomena of destruction of a metal by chemical or electrochemical reaction with its environment. Under frame and bogie are the main parts in a coach that is subjected to corrosion because of the presence of lavatory. Mechanical strength is reduced and the section ultimately fails if extensive corrosion occurs. Corrosion and its control is an important, but often neglected element in the practice of engineering. Taking care right from the material selection to successful operation, adhering to the guidelines is the only possible way to minimize losses. Corrosion is a term related to material deterioration mechanism, which may induce flaws affecting the health of components. If these flaws are not detected at the right time, they may lead to the failure of the component resulting in loss, productivity and threat to safety.

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K.Velayutham, BIT Campus, University College of Engineering, Tiruchirappalli, 620024, TN India.

U.Arumugham, BIT Campus, University College of Engineering, Tiruchirappalli, 620024, TN India .

B.Kumaragurubaran, BIT Campus, University College of Engineering, Tiruchirappalli, 620024, TN India.

P.Gopal, BIT Campus, University College of Engineering, Tiruchirappalli, 620024, TN India.

To select or extract various methods of corrosion prevention methods and techniques, various technical journals are referred. Then the possible, economic, eco-friendly method of prevention methods are derived from literature acquired data for corrosion prevention purposes and a universal methodology to conduct the experimentation with a minimum number of runs is described. Finally in the last section of conclusion column the possible techniques to be applied in corrosion prevention with their advantages and drawbacks as regards facilitating their selection according to the optimization purpose.

A. Causes of Corrosion in Bogie Components

- Leakage of water through lavatory flooring.
- Missing of corrode chute and drainpipe.
- Defective water pipe fittings.
- Absence of surface preparation during replacement of commode and drainpipes.
- Habits of flushing the bogies with the water jet for cleaning.
- Striking of flying ballast when the train is running.

B. Area Subject to High Rate of Corrosion in Bogie Components

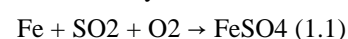
- Bogie frame: Striking of flying ballast when the train is running and lavatory water.
- Equalizing stay: Tube corrodes due to drain of lavatory water
- Brake beam: Tube corrodes due to splash of lavatory waste.
- Bogie bolster: Plates corrodes due to lavatory waste, striking of flying ballast.
- Brake levers: Plates corrodes due to lavatory waste, striking of flying ballast.

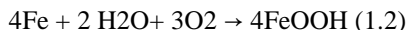
C. Five Principles to Prevent Corrosion

- Appropriate materials selection
- Change of environment
- Suitable design
- Electrochemical, i.e. cathodic and anodic protection
- Application of coatings.

The choice among these possibilities is usually based upon economic considerations, but in many cases some aspects such as appearance, environment and safety must also be taken care. Two or more of the five principles are commonly used at the same time^[4]

When unalloyed or alloyed steel without corrosion protection is exposed to the atmosphere, the surface will become reddish - brown color after a short time. This reddish - brown color indicates rust formation and the steel is corroding. In a simplified way, the corrosion process of steel progresses and is chemically based on the following equation:





The corrosion processes begins when a corrosive medium acts on a material. Since (energy - rich) base metals recovered from naturally occurring (low - energy) ores by means of metallurgical processes tend to transform to their original form, chemical and electrochemical reactions occur on the material's surface.

According to DIN EN ISO 8044, corrosion is defined as: " Physical interaction between a metal and its environment which results in changes of the metal's properties and which may lead to significant functional impairment of the metal, the environment or the technical system of which they form a part. "

D. Epoxy Coatings

Epoxy is both the basic component and the cured end product of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy resins, also known as polyepoxides are a class of reactive prepolymers and polymers which contain epoxide groups. Epoxy resins may be reacted (cross-linked) either with themselves through catalytic homopolymerisation or with a wide range of co-reactants including polyfunctional amines, acids (and acid anhydrides), phenols, alcohols, and thiols. These co-reactants are often referred to as hardeners or curatives, and the cross-linking reaction is commonly referred to as curing. Reaction of polyepoxides with themselves or with poly functional hardeners forms athermosetting polymer, often with strong mechanical properties as well as high temperature and chemical resistance.

Epoxy resins are low molecular weight pre-polymers or higher molecular weight polymers which normally contain at least two epoxide groups. The epoxide group is also sometimes referred to as a glycidyl or oxirane group.

A wide range of epoxy resins are produced industrially. The raw materials for epoxy resin production are today largely petroleum derived; although some plant derived sources are now becoming commercially available (e.g. plant derived glycerol used to makeepichlorohydrin).

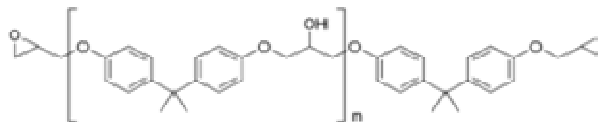
Epoxy resins are polymeric or semi-polymeric materials, and as such rarely exist as pure substances, since variable chain length results from the polymerisation reaction used to produce them. High purity grades can be produced for certain applications, e.g. using a distillation purification process. One downside of high purity liquid grades is their tendency to form crystalline solids due to their highly regular structure, which require melting to enable processing.

An important criterion for epoxy resins is the epoxide content. This is commonly expressed as the epoxide number, which is the number of epoxide equivalents in 1 kg of resin (Eq./kg), or as the equivalent weight, which is the weight in grams of resin containing 1 mole equivalent of epoxide (g/mol). One measure may be simply converted to another: Equivalent weight (g/mol) = 1000 / epoxide number (Eq. /kg)

The equivalent weight or epoxide number is used to calculate the amount of co-reactant (hardener) to use when curing epoxy resins. Epoxies are typically cured with stoichiometric or near-stoichiometric quantities of curative to achieve maximum physical properties.

As with other classes of thermoset polymer materials, blending different grades of epoxy resin, as well as use of additives, plasticizers or fillers is common to achieve the desired processing and/or final properties, or to reduce cost.

Use of blending, additives, and fillers is often referred to as formulating.



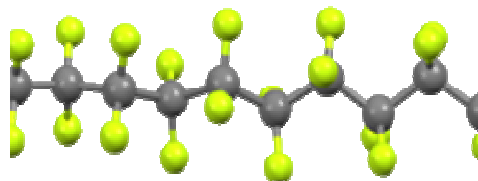
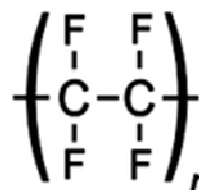
Bisphenol A Form

E. Polytetrafluoroethylene (Teflon) Coating

Polytetrafluoroethylene (PTFE) PTFE is a fluorocarbon solid, as it is a high-molecular-weight compound consisting wholly of carbon and fluorine. PTFE is hydrophobic: neither water nor water-containing substances wet PTFE, as fluorocarbons demonstrate mitigated London dispersion forces due to the high electronegativity of fluorine. PTFE has one of the lowest coefficients of friction against solid.

Other names Synolon, Fluon, Poly (tetrafluoroethene), Poly (difluoromethylene), and Poly (tetrafluoroethylene).The best known brand name of PTFE is Teflon .These retain the useful PTFE properties of low friction and non-reactivity, but are more easily formable. For example, FEP is softer than PTFE and melts at 533 K (260 °C; 500 °F); it is also highly transparent and resistant to sunlight.

It is formed by the polymerization of tetrafluoroethylene



Polytetrafluoroethylene Form

TABLE I
POLYTETRAFLUOROETHYLENE PROPERTY

Molecular formula	(C ₂ F ₄) _n
Density	2200 kg/m ³
Melting point	600 K
Coefficient of friction	0.05–0.10
Yield strength	23 MPa

The coefficient of friction of plastics is usually measured against polished steel. PTFE's coefficient of friction is 0.05 to 0.10 which is the third-lowest of any known solid material.

II. METHODOGLY

A. Test Method of Salt Spray [Fog] Testing

The oldest and most wildy used cabinet test is ASTM B117 (Test Method of Salt Spray [Fog] Testing), a test that

introduces a spray in a closed chamber where some specimens are exposed at specific locations and angles. The concentration of the NaCl solution has ranged from 3.5 to 20%. There is a wide range of chamber designs and sizes including walk-in rooms that are capable of performing this test. Although used extensively for specification purposes, results from salt spray testing seldom correlate well with service performance. Hot, humid air is created by bubbling compressed air through a bubble (humidifying) tower containing hot deionized water.

Salt solution is typically moved from a reservoir through a filter to the nozzle by a gravity-feed system. When the hot, humid air and the salt solution mix at the nozzle, it is atomized into a corrosive fog. This creates a 100% relative humidity condition in the exposure zone. For a low humidity state in the exposure zone of the chamber, air is forced into the exposure zone via a blower motor that directs air over the energized chamber heaters.

According to Robert Baboian:

"The salt spray fog test, when it's used properly, is one of the most valuable corrosion tests in the world. It has impacted all industries. It has been very valuable in terms of quality control and comparative behavior materials and that's in all walks of life: in the automotive, aircraft and compliance industries, in transportation and infrastructure. Paint coatings are used in all of these industries."

"The test is used widely for paint systems. When it's used properly, for quality control or comparing behavior of materials, it is extremely valuable. For example, cyclic tests that are used now in various industries incorporate the use of B 117. These tests are extremely valuable because they more closely duplicate what happens in service."

B. Test Method of Acid Immersion Testing

The environmental conditions that must be simulated and the degree of acceleration that is required often determine the choice of a laboratory test. In immersion testing, acceleration is achieved principally by: (reference)

- Lengthening the exposure to the critical conditions that are suspected to cause corrosion damage. For example, if a vessel is to be batch-processed with a chemical for 24 h, then laboratory corrosion exposure of 240 h should be considered
- Intensifying the conditions in order to increase corrosion rates, i.e. increasing solution acidity, salt concentration, temperature or pressure etc.

Once the environmental conditions have been determined, and the test designed, then it should be repeated a sufficient number of times to determine whether it meets the desired standard for reproducibility. Immersion tests can be divided into two categories:

Simple immersion tests: basically small sections of the candidate material are exposed to the test medium and the loss of weight of the material is measured for a period of time. Immersion testing remains the best method of screening and eliminating from further consideration those materials that should not be considered for specific applications. But while these tests are the quickest and most economical means for providing a preliminary selection of best suited materials, there is no simple way to extrapolate the results obtained from these simple tests to the prediction of system lifetime.

Alternate immersion tests: another variation of the immersion test is the cyclic test procedure where a test

specimen is immersed for a period of time in a test environment, then removed and dried before being re-immersed to continue the cycle. Normally hundreds of these cycles are completed during the course of a test program.

C. Related Work

The degree of sensitization and susceptibility to intergranular corrosion were assessed by electrochemical potentiokinetic reactivation and weight loss tests respectively. The grain boundary character distribution was established by orientation imaging microscopy.^[1]

Corrosion is prevented or at least decelerated through the isolation of the metal material from the corrosive agent by the applied protective layers.^[4]

Electrochemical and immersion tests were carried out for SS 304L at 80 °C in 2 M nitric acid containing hydrazine and formaldehyde. The addition of hydrazine resulted in the higher anodic current and no appreciable change in weight loss.^[8]

The coating is electrochemically characterised in simulated body fluid at 37 °C after 1, 10 and 30 days of immersion by means of assays as electrochemical impedance spectroscopy (EIS) and polarization curves.^[11]

The corrosion tests were performed in 3.5 wt.% NaCl aqueous solution. The corrosion tests of the PPy coated steel were carried out at 25.0 ± 0.3 °C in 3.5 wt.% NaCl solution in which the open circuit potential (OCP) was continuously recorded for 7 or more days.^[15]

All the specimens for erosion, corrosion and electrochemical testing were in the form of plates with dimensions: 50mm length, 25mm width and 2mm thickness. The specimens were polished using SiC abrasive papers, #180 to #600 grit, before they were subjected to heat treatment, erosion–corrosion testing and electrochemical measurements.^[18]

The dimension of specimen was 12 x 35 x 2.5 mm. The experimental results provide a basis for the application of impedance spectroscopy in non-destructive evaluation of thermal barrier coatings.^[20]

D. Standard Expression for Corrosion Rate

A good corrosion rate expression should involve

- Familiar units
- Easy calculation with minimum opportunity for error
- Ready conversion to life in years
- Penetration and
- Whole numbers without cumbersome decimals.

The formula for calculating the rate is:

Miles per year = $534 W/DAT$

Where W= weight loss in mg

D = density of specimen in g/cm³

A = area of specimen sq.in

T = exposure time hrs.

III. EXPERIMENTAL DETAILS

A. General

Two different coating systems were considered for evaluation as follows. The coating system chosen were: (1) Epoxy coating (2) Polytetrafluoroethylene (Teflon) coating.

The substrate material was 5 mm thick steel to IS: 2062/2006 of Grade E250 (Fe 410W) Quality B representing

the main material composition of frame, equalising stay and break beam of bogie components.

Different experimental system:

TABLE II
TEST PIECE IDENTIFICATION

ID	Coating	Test methods
ES	Epoxy coating	Salt fog
TS	Teflon coating	Salt fog
EC	Epoxy coating	Sulphuric acid immersion
TS	Teflon coating	Sulphuric acid immersion

B. Preparation of Panels (Test Piece)

Steel panels used for testing shall be of mild steel to IS:2062/2006 of Grade E250 (Fe 410W) Quality B of chemical composition C-0.22%, Mn- 1.50%, S – 0.045%, P – 0.045% and Si – 0.40% Carbon Equivalent (CE) 0.41 Maximum. Steel panels are to be fully finished of deep drawing quality, size 50 × 50 × 5 mm, free from surface imperfections, such as rolling marks and scores and scale, and shall be commercially available flat skin passed high grade sheet with minimum surface blemishes suitable for a high standard of surface finish^[2]

Before use, wipe the mild steel panels free from excess oil, roughly degrease with petroleum hydrocarbon solvent and burnish uniformly with IS Grit No. 180 emery cloth. Burnish lightly with petroleum hydrocarbon solvent conforming to avoid embedding emery in the surface. The burnishing operation by the use of power tools shall be as follows:

- a) Straight across the panel, in a direction parallel to any one side;
- b) Perpendicular to first direction and until all signs of original burnishing have been obliterated; and

With a circular motion of diameter approximately 75 mm, until a pattern consisting of circular burnishing marks superimposed one upon another is produced. Remove the traces of emery dust by wiping with a linen rag. Degrease the panel by swabbing two or three times with a linen rag, soaked in suitable hydrocarbon solvent.

Final swabbing shall be done with a clean rag soaked in clean hydrocarbon solvent. Dry the panels slightly to remove traces of condensed moisture allow returning to room temperature and then painting without delay. The prepared surfaces should not be touched by hand or otherwise between degreasing and painting.

C. Procedure for Creating Surface Finish of Panels

The material when applied on a mild steel panel by brushing or spraying, whichever is specified and allowed to dry for 48 hours in a vertical position under specified conditions in dust free atmosphere, shall dry to a hard, firmly adherent, flexible and smooth film, free from sagging and wrinkling, with a matt semi glossy or glossy surface in accordance with the requirements of the material specification.

D. Procedures for Resistance to Salt Water

Test liquid is Salt water of NaCl 3.5 wt. % solution. The test shall be carried out at a temperature of 27 ± 2°C. It is preferable to immerse the test pieces individually in the test liquid. In certain cases however, it may be more convenient to

immerse several test pieces in a single tank; in these cases, the nature of the test pieces shall be identical and every precaution shall be taken to ensure that the test liquid is unaffected by the test pieces.

The test pieces shall be at least 30 mm from the sides of the tank and if several pieces are immersed in the same tank, they shall be at least 30 mm apart. The test pieces shall be electrically insulated from their supports. Place sufficient amount of liquid in a suitable vessel to completely or partially immerse the test pieces (rod or panel). Immerse the test piece in an approximately vertical position using suitable supports, if necessary.

Cover the container for the duration of the test to minimize the loss of liquid by evaporation or splashing. At the end of the 15 min immersion period, remove the panel and exposure in air and sun light for a period of 8 hours and then immersed in salt water for a period of 15 min. This process is to be repeated for 7 days, 14days and 21 days.

After the exposure, weigh the test piece in 0.001 mg accuracy and comparing with the identically prepared another type of coated test piece by magnifying the appearance (X 200 scale) and recorded.

E. Procedure of Resistance to Liquids Test

Test liquid is 25% (v/v) sulphuric acid solution. The test shall be carried out at a temperature of 27 ± 2°C. It is preferable to immerse the test pieces individually in the test liquid. In certain cases however, it may be more convenient to immerse several test pieces in a single tank; in these cases, the nature of the test pieces shall be identical and every precaution shall be taken to ensure that the test liquid is unaffected by the test pieces.

The test pieces shall be at least 30 mm from the sides of the tank and if several pieces are immersed in the same tank, they shall be at least 30 mm apart. The test pieces shall be electrically insulated from their supports. Place sufficient amount of liquid in a suitable vessel to completely or partially immerse the test pieces (rod or panel). Immerse the test piece in an approximately vertical position using suitable supports, if necessary.

Cover the container for the duration of the test to minimize the loss of liquid by evaporation or splashing. At the end of the 10 min immersion period, remove the panel and exposure in air and sun light for a period of 8 hours and then immersed in the liquid for a period of 10 min. This process is to be repeated for 7 days, 14 days and 21 days^[11]

After the exposure period weigh the test piece in 0.001 mg accuracy and comparing with the identically prepared another type of coated test piece by magnifying the appearance (X 200 scale) and recorded.

IV. RESULT AND DISCUSSION

A. Result

There exist numerous standardized procedures for testing the corrosion rates are salt fog method and loss of weight. The specimens are subjected to the above mentioned test with atmospheric exposure of 7 days, 14 days and 21 days and the various parameters required for calculations are measured. Collected data are verified with sample ID and tabulated.

B. Optical Microscope Image after Salt Fog Test

Fig 4.1(a & b) shows the microscopy images of mild steel

epoxy coated test panel, tested under the condition of immersed in NaCl 3.5% wt. solution and exposure in air as per procedure mentioned earlier. The test panels were coated with epoxy painted with standard coating procedure. The tests are conducted at room temperature ($27 \pm 2^\circ\text{C}$) and relative humidity at $65 \pm$ in a well-ventilated chamber free from draughts and dust. The temperature of the surface to be painted must be at least 3°C above the dew point prevent moisture condensation.

After the surface preparation of panel, the two components of epoxy coated resins i.e. base and hardener shall be mixed in the ratio of 1: 1 and applied on the panels by using spray application.

Fig 4.2 shows the microscopy images of mild steel Teflon coated test panel, tested under the condition of immersed in NaCl 3.5% wt solution and exposure in air as per procedure mentioned earlier. The test panels were coated with Teflon painted with standard coating procedure. The tests are conducted at room temperature ($27 \pm 2^\circ\text{C}$) and relative humidity at $65 \pm$ in a well-ventilated chamber free from draughts and dust. The temperature of the surface to be painted must be at least 3°C above the dew point prevent moisture condensation.

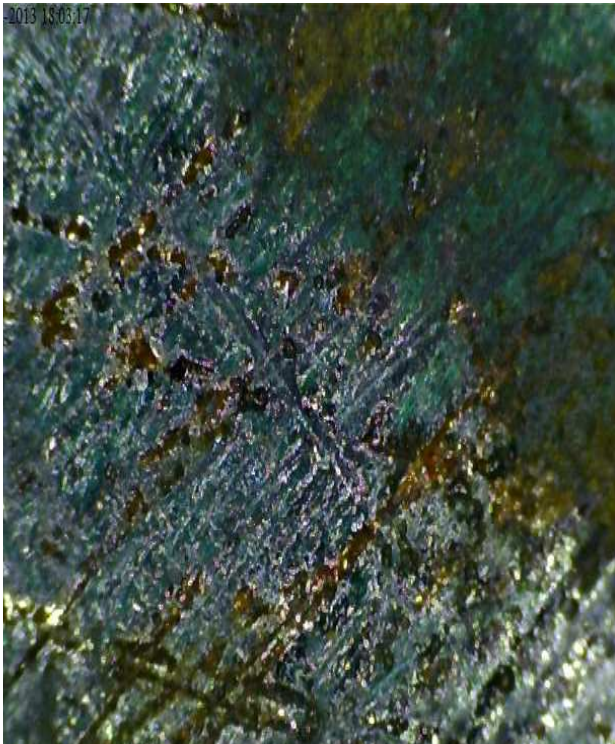


Fig 4.1(a) Image of epoxy coated after 168 hrs salt immersion test. (Scale X200)



Fig 4.1(b) Image of epoxy coated after 168hrs. salt immersion test.



Fig 4.2 Image of Teflon coated after 168 hrs. salt immersion test.

After the surface preparation of panel, the Teflon coated is applied on the surface and cured at 350°C for 6 hours and taken out from oven. The oven is calibrated one and temperature differences are to be within 5°C .

The images are obtained by 200 X scale and recorded.

C. Optical Microscope Image after Acid Immersion Test

Fig 4.3 (a –d) shows the microscopy images of mild steel epoxy coated test panel, tested under the condition of immersed in 25% (v/v) Sulphuric acid solution and exposure in air for 168 hrs. The test panels were coated with epoxy painted with standard coating procedure. The tests are conducted at room temperature ($27 \pm 2^\circ\text{C}$) and relative humidity at $65 \pm$ in a well-ventilated chamber free from draughts and dust. The temperature of the surface to be painted must be at least 3°C above the dew point prevent moisture condensation.

After the surface preparation of panel, the two components of epoxy coated resins i.e. base and hardener shall be mixed in the ratio of 1: 1 and applied on the panels by using spray application. At the end of the 10 min immersion period, remove the panel and exposure in air and sun light for a period of 8 hours and then immersed in the liquid for a period of 10 min. process is to be repeated for 7 days, 14 days and 21 days



Fig 4.3(a) Image of epoxy double coated after 168 hrs acid immersion test.



Fig 4.3(d) Image of epoxy single coated after 168 hrs acid immersion test(scale X200)

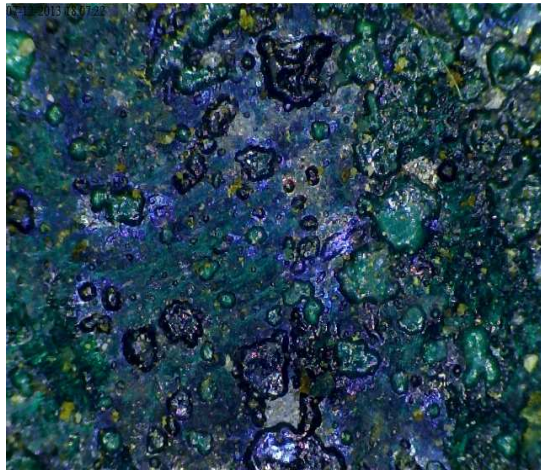


Fig 4.3(b) Image of epoxy double coated after 168 hrs acid immersion test. (Scale X200)

After the surface preparation of panel, the Teflon coated is applied on the surface and cured at 350 ° C for 6 hours and taken out from oven. The oven is calibrated one and temperature differences are to be within 5 °C.

At the end of the 10 min immersion period, remove the panel and exposure in air and sun light for a period of 8 hours and then immersed in the liquid for a period of 10 min. process is to be repeated for 7 days, 14 days and 21 days

The images are obtained by 200X scale and recorded.



Fig 4.3(a) Image Teflon coated after 168 hrs acid immersion test

Fig 4.4 shows the microscopy images of mild steel Teflon coated test panel, tested under the condition of immersed in 25% (v/v) sulphuric solution and exposure in air for 168 hrs. The test panels were coated with Teflon painted with standard coating procedure. The tests are conducted at room temperature (27 +/- 2°C) and relative humidity at 65 +/- in a well-ventilated chamber free from draughts and dust. The temperature of the surface to be painted must be at least 3°C above the dew point prevent moisture condensation.

C. Loss of Weight after Immersion Test

The formula for calculating the corrosion rate is:

$$\text{Miles per year} = 534 \text{ W/DAT}$$

Where

W= weight loss in mg

D = density of specimen in g/cm²

A = area of specimen sq.in

T = exposure time hrs.

From the above formula we calculate the corrosion rate on miles per year.

The mpy values are calculated and obtain comparative values as shown in fig 4.6



Fig 4.3(c) Image of epoxy single coated after 168 hrs acid immersion test

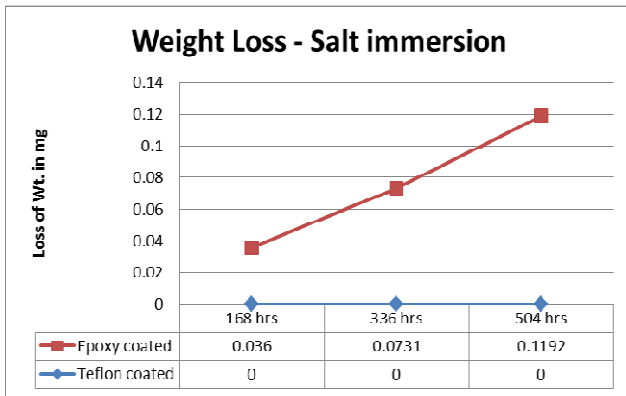


Fig 4.4 Weight loss comparison after salt immersion test.



Fig 4.5 Weight loss comparison after acid immersion test

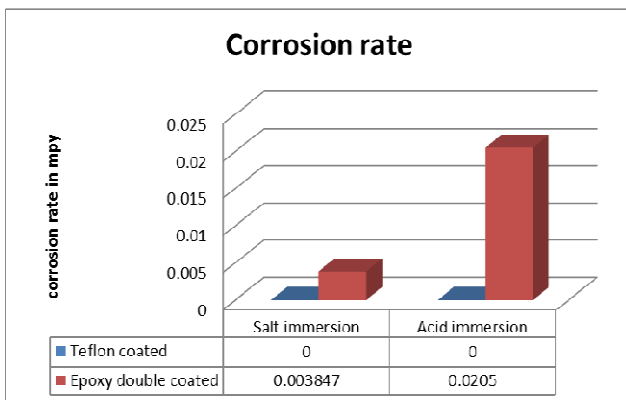


Fig 4.6 Corrosion rate comparison

V. CONCLUSION

Salt fog test and Sulphuric acid immersion corrosion tests were carried out under high relative humidity condition. Corrosion rate of all test panels and the images of coating surfaces affected by corrosion are summarised in the previous chapter.

By comparing the above data Teflon coated surfaces are much fine finish and corrosion resistant than the epoxy coated.

By this study we conclude that the Teflon can replace the epoxy coating in the equalising beam, brake beam and bogie frame and it can withstand the corrosion due to the waste water release from lavatory and ballast hiding. By applying this, the renewal period of the components can be increased by 1.7 times than earlier. The total cost of the corrosion repair can be reduced.

We have derived the result based on maximum 504 hrs atmospheric exposures only. During this time the Teflon coating panels does not lose any weight. A study of 2000 hrs experimental periods is under progress and result will be produced later.

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K.Velayutham ME final year student in Anna University college of Engineering, Tiruchirappalli. He received his diploma in DME in the year 1984 and completed his AMIE (I) in 1992. He is having 22 years' experience in Railway drawing department. Currently he



is working as a Senior Section Engineer/Drawing in Railway workshop.

U. Arumugham ME final year student in Anna University college of Engineering , Tiruchirappalli. He received his diploma in DME in the year 1982 and completed his BE in 2009. He completed his PGDOM in 2004 and PGDPM & IR in 2012. He is having 29 years' experience in production line, Automotive Manufacturing sector. Currently he is working as Deputy General Manager in production line.



B. Kumaragurubaran is working as an Asst. Professor in in Anna University College of Engineering, Tiruchirappalli. He received his BE from University Of Madras in the year 2003 and did his ME from Annamalai University, Chidambaram 2005. He is pursuing Ph.D in engineering material. He is having 7 years of experience in the field of teaching. He has attended 18 conferences and he has published 7 national and international journals. He is life member in Indian Welding Society from 2004.



P. Gopal, B.E.(Mech), M.E.(Auto) is working as an Head of the Department in Anna University College of Engineering, Tiruchirappalli. He is having 13 years of experience in the field of teaching. He has attended 24 National and international conferences and he has published 8 national and international journals.