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# Review on Erosion and Corrosion Studies on Steel Weldments

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**ABSTRACT:** This paper presents the extensive literature review conducted on erosion and corrosion studies carried out in various grades of steel weldments used in applications such as chemical and processing industries. The various grades of steel pipes are employed in the above stated application for the transportation of hot gases and oils. At high temperature environmental conditions, the weldments are prone to erosion and corrosion which will deteriorate the life cycle of the weldments. Hence the detailed study on erosion types, erosion behaviour, erosion mechanism and metallurgical characteristics changes occurring with respect to mechanical properties at various environmental conditions in various steel grade pipes is very important in estimating the life cycle of the weldments. Similarly, the corrosion occurring in steel pipes and also at welded pipe joints will also lead to premature failure of the components. Through SEM images, types of corrosion, corrosion mechanism was discussed in detail in this paper. The main objective of this literature survey is to gather salient points of the previously carried out research works with reference to erosion and corrosion studies, so that it will provide the strong base for carrying out experimental investigations onbutt welded A106 Grade-B pipes for estimating its erosion and corrosion resistance under acidic and alkaline conditions .

**KEYWORDS: Erosion, Corrosion, SEM, Weldment, Carbon steel**

## 1. INTRODUCTION

### 1.1. Erosion:

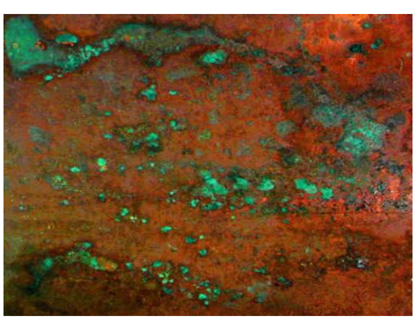

**Figure.1.Erosion in metallic specimen**

The particulate breakdown of metal into clastic sediment is referred to as physical or mechanical erosion. In material erosion,the inside of the material does not degrade until all the surrounding material around it has been degraded. There are two types of material erosion: they are, Surface erosion and Bulk erosion. In surface erosion, the erosion rate is directly proportional to the surface area of the material but in bulk erosion, the erosion rate depends on the volume of the material.

### 1.2. Corrosion:

Corrosion is a process, which converts a refined metal to a more chemically stable form, such as its oxide, hydroxide, or sulphide. It is the gradual destruction of materials by chemical or electrochemical reaction with their environment. Rusting, the formation of iron oxide is a well-known example of electrochemical corrosion. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases. When a material corrodes, it changes and becomes weaker. There are different types of corrosion: they are Galvanic corrosion, Stress-corrosion cracking, General corrosion, Localized corrosion, Caustic agent corrosion, Environmental cracking, Flow-assisted corrosion, intergranular corrosion, De-Alloying, Fretting corrosion, High Temperature corrosion.

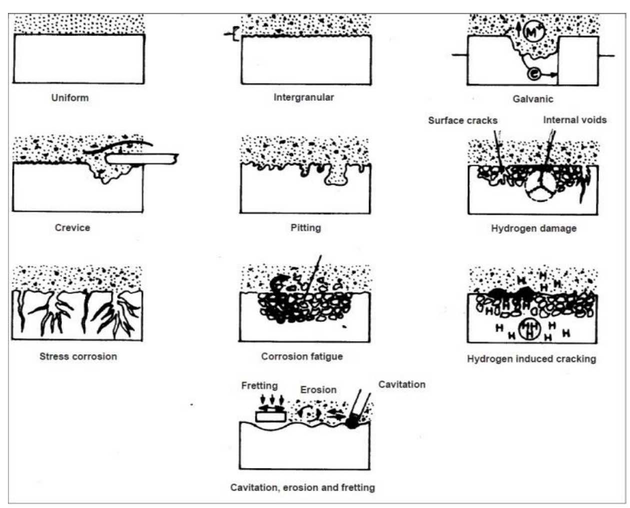


**Figure 2.Tyes of Corrosion**

### 1.3.Combined Erosion-Corrosion

Combined Erosion and Corrosion is a degradation of material surface due to the mechanical action, often by impinging liquid, abrasion by a slurry, particles suspended in fast flowing liquid or gas, bubbles or droplets, cavitation, etc. The mechanism of erosion and corrosion is the materials affected by it, and the conditions when it occurs are generally different from that of flow-accelerated corrosion.

In the extensive literature review we discussed in detail about the types of erosion and corrosion on various materials and its behaviour, property changes, experimentation carried out, analysis of the effect etc., In the following sections, the studies carried out in erosion and corrosion on various steel materials probably the pipes used in chemical and processing industries were discussed.

### 2.1. Erosion

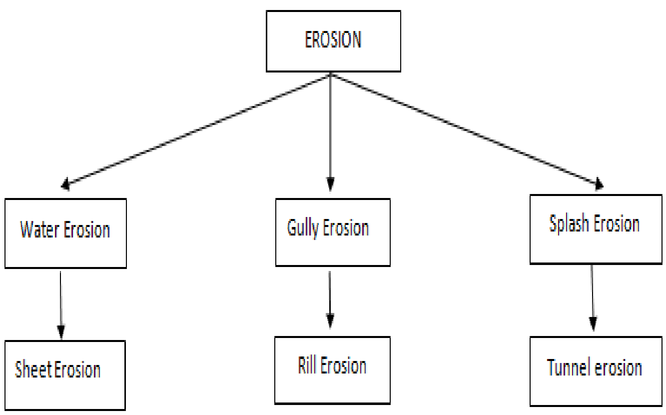


**Figure.3. Classification of Erosion**

### 2.1.1. Erosion studies in slurry pot tester

**Humphery** et al conducted experiment on accelerated erosion in a slurry pot tester. The parameters considered are temperature, the particle concentration and size distribution, the viscosity and the particle and fluid phase velocities.. The experiment is done to optimize the errors in coal liquefaction process. The purpose of an accelerated erosion device is to force erosive wear at an accelerated rate, From their results, it was erodent that used in the process helps to minimize the corrosive effects.[1]

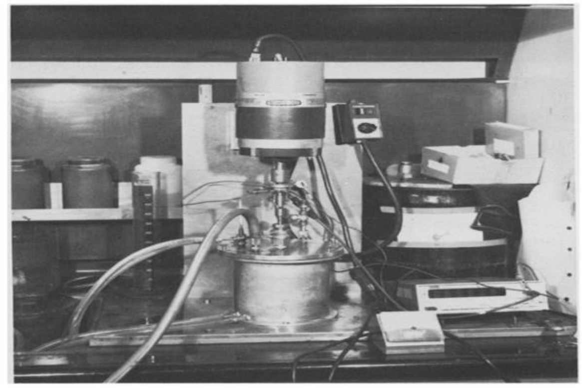

**Figure.4. Slurry pot tester**

Similarly, **Sehadri** et al investigated the uneven wear in a slurry pipeline using pot erosion tester. They suggested that erosion wear was directly proportional to velocity. They carried out a systematic study on the phenomenon of abrasion wear in slurry pumps and has shown that wear is dependent on velocity, concentration, particle diameter, impingement angle and relative hardness.[2]

### 2.1.2. Erosion behaviour under larger abrasive particles

**Ojala** et al inspected the steel material for its corrosion resistance and hardness. Moreover, Steel samples were used for checking the consistency of the tests. The abrasive size could be increased by using shorter samples, but that would change the slurry flow conditions. According to their study, the wear rate is decreasing because of the progressive commination of the abrasive particles[3]

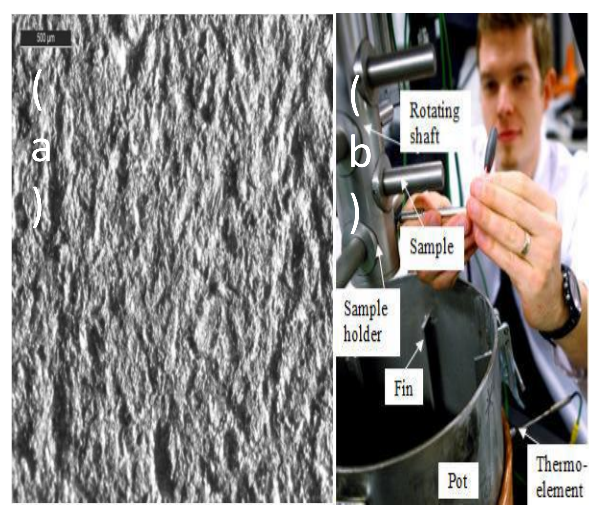


**Figure.5 (a, b) shows the SEM image of the eroded materials and erosion tester**

### 2.1.3. Effect of various parameter in slurry pot erosion tester

#### (i) Impact angle

**Clark** et al calculated the impact angle, particle energy, mass loss in slurry erosion. The particle impact event in erosion has been examined by in terms of impulse and momentum, using the coefficient of restitution. Erosion of a ductile target by particles at normal impact is less rapid than at intermediate angles. They also investigated the S45C carbon steel. In their experiment study, duration of time period was used to evaluate the surface damaging of the carbon steel and mild steel in the mixtures of tap water and sand with 1% wt sodium chloride.[4&5]

#### (ii) Particle size

**Borse** et al observed that the wear increases with increase in particle size. They also observed that the maximum erosion occurs at some intermediate particle size except for ceramic eroding surfaces.

Variation of erosion rate change with particle size or to the change in the particle mass. The median or weighted mean size of multi-sized particulate slurries having continuous particle size distributed (PSD) has been used to estimate erosion wear.[6]

#### (iii) Based on the impact rate, energy and velocity

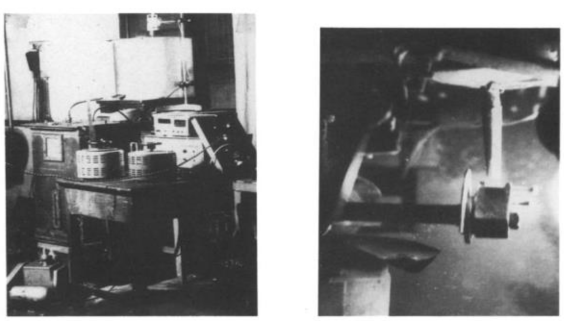

**Figure.6. Surface morphology of specimen**

**Lin** et al observed that the slurry works well with a 20 wt.%, 120 grit, quartz sand-water slurry. The system also works well with some larger grit sizes or denser abrasives but in a lower solid particle loading slurry.[7]

### 2.1.4. Erosion behaviour of materials under hostile atmospheric conditions

**Tylczak** et al observed that the silica, chosen as the erodent causes the most of the erosion. The feed of the silica is given accordingly to the wastage rate . The feed rate of the silica sand was adjusted to produce the target wastage rate (with the estimated feed rate in the range of 0.05 to 0.5 g/minute), and the time of the test was the minimum time to produce useful weight losses. The samples are weighted and again examined visually.[8]

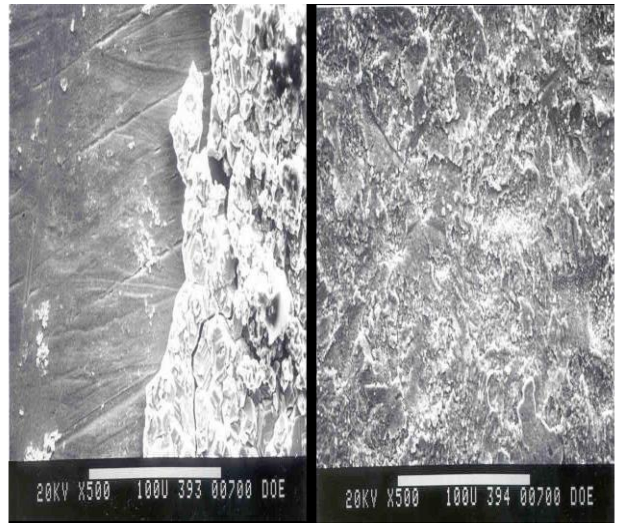


**Figure.7. SEM morphology of erosion in material**

### 2.1.6. Erosion Studies on the Ductile materials

**Jain** et al observed the erosion behaviour on AA6063 and AISI 304L materials. Three different natural erodent's namely, quartz, alumina and silicon carbide have been used to form solid–liquid mixtures with water. The SEM photographs were taken for each erodent's. Experiments were performed for 10% weight concentration of solid particles at the velocity of 3 m/s. [9]

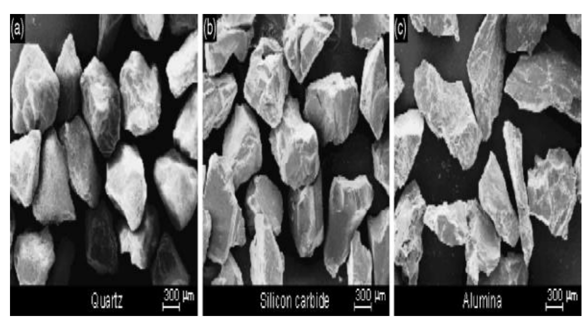


**Figure.8. Surface morphology of specimen**

**Ghandi** et al observed the slurry erosion of ductile materials under the normal impact conditions. The erodents namely quartz, alumina and silicon carbide have been mixed with water to prepare different solid–liquid mixtures, done for 8 materials namely mild steel, copper, brass, aluminium alloy, AISI 304L stainless steel, AISI

316L stainless steel, and turbine blade steel. The coefficient of variation for average mass loss is observed as 8.3%, which shows that the measurement of mass loss does not lead to scatter of more than 8.3%.[10]

Corrosion is one of the most predominant causes of pipeline failures in oil and gas production and accounts for between one quarter to two third of the total downtime in the industry. The existence of CO2, H2S, organic and inorganic acids in a pipeline operating environment may cause corrosion defects of different sorts. The corrosion defects are caused by the electrochemical reaction of water and iron content of the pipeline material in the presence of CO2(sweet corrosion), H2S (sour corrosion) and/or microorganisms(microbiologically induced corrosion).

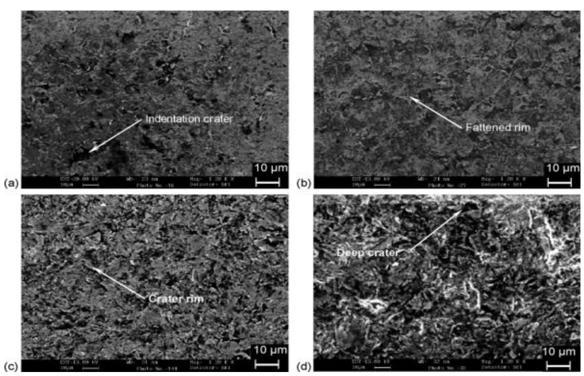


**Figure.9. Surface morphology of specimen**

### 2.1.7. Erosion behaviour under varying flow geometry & flow field

**Clark** et al conducted the erosion tests using black silicon carbide. Fresh erodent was used for each test. In wear measurement, the surface profile was measured at the same locations before and after erosion by rotating the specimen axially using stepper motors beneath the sensing needle of an linear variable differential transformer (LVDT)[11]

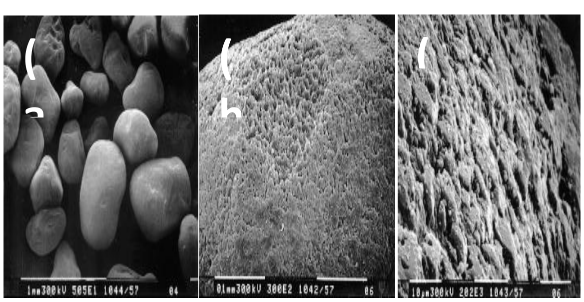

**Figure.10 (a, b, c) shows the Surface morphology of specimen**

## 2.2. CORROSION

Corrosion is the process of corroding or being corroded. Corrosion is normally defined as the deterioration of a metal or its properties caused by a reaction with its environment. Most metals naturally occur in form of oxides and are usually chemically stable. When exposed to oxygen or any other oxidizing agents, the refined metal will try to revert to its natural oxide state. In the case of iron, the oxides will be in the form of ferric oxide, which is known as rust. The corrosion behaviour and its effect on materials like Carbon A106 Steel, Stainless steel were discussed in detail in this section.

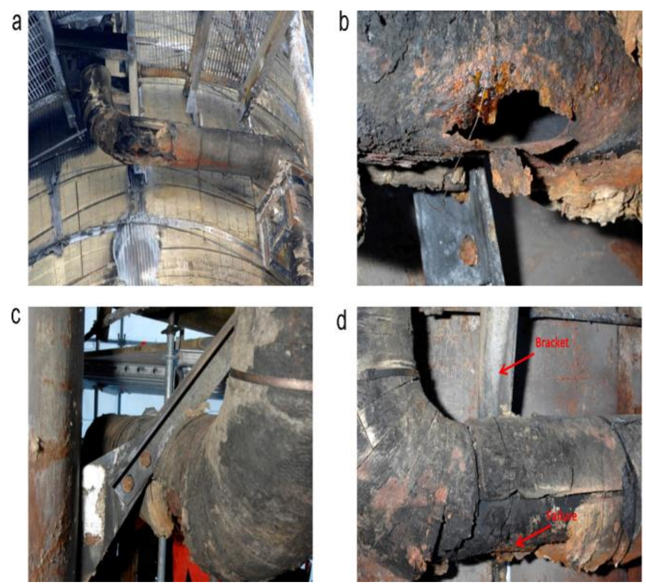


**Figure.11. (a) Position of failure of process pipe work, (b) detail of pipe work fracture, (c) walkway bracket interaction with pipe work lagging, (d) pipe work bracket and failure (indicated).**

### 2.2.1. Corrosion in Pipelines

Corrosion normally occurs in pipeline, metals, industrial materials, etc, due to oil, gas or some other chemicals. But Pipeline corrosion is a major challenge facing in industries due to the enormous downtime associated with corrosion related failures. The corrosion reaction produces protective scales such as FeCO3, CaCO3 and FexSx but hydrodynamic force in the fluid flow leads to more corrosion.

**Figure.12. Corrosion in pipelines**

Carbon steel materials are more susceptible to stress corrosion cracking at reduced potentials and fatigue failure on Corrosion Resistance Alloys. Pipeline corrosion cannot be eliminated entirely, it is imperative that optimal performance of pipelines can be achieved based on integrity assurance cycle.[12]

### 2.2.2. Corrosion Testing of Welds

A number of tests are used to establish the corrosion resistance of carbon steels, stainless steels and nickel alloys. The susceptibility to general corrosion of a material is studied by immersion of a test material in a specified corrosive environment for a certain period of time. The corrosion rate is determined by measuring the mass loss. The forms of corrosion considered are:

– General corrosion
– Stress corrosion
– Pitting corrosion
– Corrosion fatigue
– Intergranular corrosion
– Galvanic corrosion
– Crevice corrosion
–Field testing

Based on the guidelines in the ASTM G48 standard, the applied testing procedure includes the additional efforts to evaluate different effects related to weight-loss and location of pits. The consecutive testing procedure can be summarized as follows:

1. Coupon cutting, registration of clockwise orientation in respect to weld
2. Coupon marking
3. Pre-examination
4. Cut face preparation and degreasing
5. Weighing
6. Pickling (none, paste or dip)
7. Weighing
8. Exposure
9. Post-cleaning
10. Weighing

### 2.2.3. Materials and Methods used to analyze the corrosion rate:

In this section, we majorly discuss about corrosion on A 106 material and other steels. A 106 is a carbon steel pipe with excellent mechanical properties and thermal resistance.

**Yingsamphancharoen** et al carried out the corrosion experiment on carbon steel pipe using potentiostat instrument, Auto-lab series PSGTAT 30 model. The probes of the working electrode and the counter electrode were platinum while the reference electrode was Ag/AgCl. By carrying out this experiment in

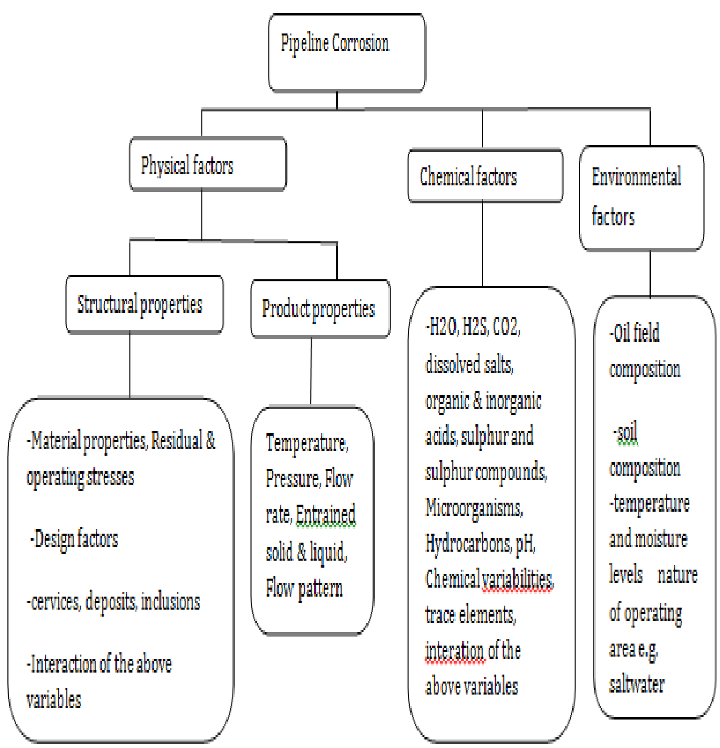


**Figure.13. Types of Corrosion in pipelines**

Presence of 3.5wt% of sodium chloride, the corrosion rate can be analyzed.[15]

**Hamada** et al examined the corrosion behavior of A106 carbon steel absorber for CO2 removal in amine promoted hot potassium carbonate solution (Benfield solution). The corrosion rate was measured by weight loss technique. The corrosion behavior of carbon steel in Benfield solution was studied in relation to the following parameters:

(i) solution velocity
(ii) % potassium carbonate
(iii) solution temperature
(iv) % [di ethanol amine (DEA)]
(v) CO2 loading
(vi) the presence of solution contaminations.[16]

Surface morphology SEM studies revealed the presence of a porous solid layer of corrosion products.

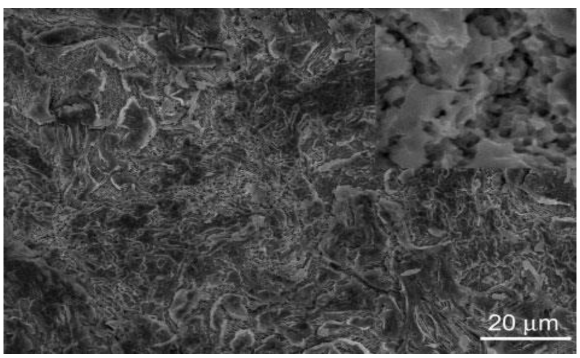


**Figure.14. SEM images of carbon steel A 106 steel**

**Sun** et al investigated the Corrosion behavior of carbon steel A106 in aqueous mono ethanolamine by performing electrochemical polarization experiments. Corrosion rates and other important parameters were calculated based on the electrochemical curves for A106. Sample surfaces after tests were examined by scanning electron microscopy and energy dispersive spectroscopy. Based on their experimentation, it was found that corrosion of A106 was intensified as temperature was increased because both anodic and cathodic reactions proceed faster.[17]

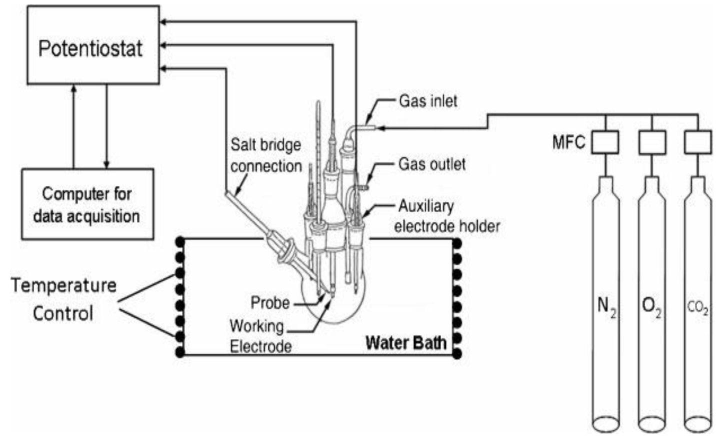


**Figure.15. Electrochemical apparatus to analyze corrosion rate**

**Zheng** et al investigated the A106 grade B carbon steel, used as seam-less pipe at high temperature and pressure for corrosion behaviour.[18]

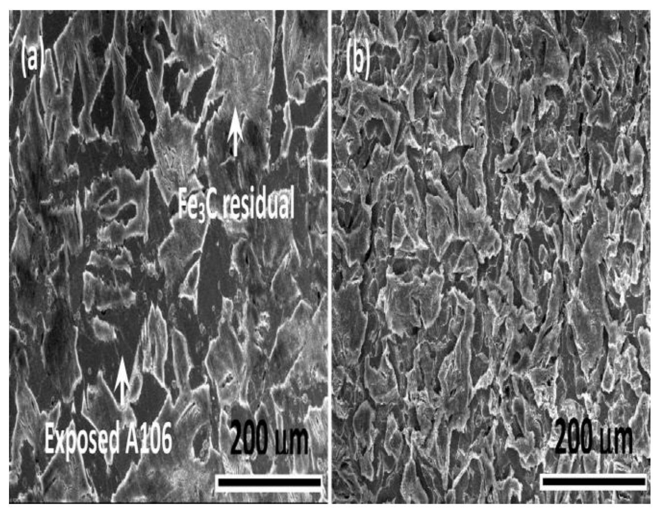


**Figure.16. SEM Surface Morphologies in carbon steel A106 pipe**

**Geary**et al analysed the corrosion under insulation failure in a carbon steel.They analysed the pipe material using an optical emission spectroscopy(OES) technique. Samples of corrosion deposits were taken for EDX analysis in the SEM. The results showed that the primary constituents were iron and oxygen together with significant quantities of sodium, chlorine and sulphur.[19]

**Subramanian** et al investigated thecarbon steel 106 Grade B pipe for corrosion behaviour. At iron unsaturated conditions, along with high fluid velocities present in the carbon steel outlet feeder elbows/piping, results in enhanced corrosion in these locations [20]

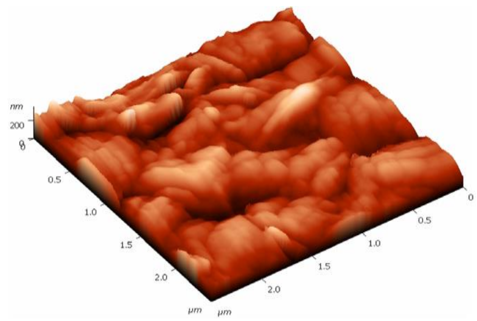

**Figure.17. Surface morphology of specimen.**

The presence of O2 and heat stable salts in MDEA-CO2 systems have been shown to slightly increase corrosion rates on carbon steel. The use of SH amines offer the opportunity to grow siderite layers on carbon steel, while some CO2 capture can take place[21]

**Kyra** et al in his paper says that significant potential for the use of carbon steel infrastructure in post-combustion capture plants where siderite provides a protective barrier on the surface. The siderite layers appear to be sufficiently robust to withstand the corrosive nature of more efficient amines.[22]

In Super duplex stainless steels (SDSS) are being increasingly used as structural materials in marine and petrochemical applications. This is mainly due to their high resistance to corrosion and stress corrosion cracking as well. The micro electrochemical investigations were used for predicting corrosion rates. [23]

In commercial super duplex stainless steels, the pitting corrosion resistance annealed at seven different temperatures ranging from 1030'C to 1200'C for 2h has been investigated by means of potentiostatic critical pitting temperature. The compositions present were measured by energy dispersive X-ray spectroscopy(EDX) linked to SEM system[24]

In addition to the corrosive environment, high fluid flow speeds are always encountered by components used in the industries. S31603 has higher pitting corrosion resistance than that of S30400 because of molybdenum[25]

The feasibility of laser surface melting using a 2 kW CW Nd-YAG laser for improving corrosion resistance of various stainless steels. After laser melting, some specimens were sectioned, polished and etched with a solution of 15ml HCl, 10 ml HNO3, 10 ml acetic acid and 5ml glycerol. The microstructure and chemical composition of the laser melted zone were analysed using scanning electron microscopy, optical microscopy and energy dispersive spectroscopy. [26]

The corrosion behavior performed using salt spray shows the higher weight loss and corrosion rate due to the aggressive environment compares to immersion test[27]
In one of the experimental method, two cylindrical electrodes made from A106 mild steel with0.8cm2 surface area are embedded inside a resin filled cylindrical probe. An electrochemical cell is formed together with an addition Ag/AgCl reference electrode cell with saturated KCl as filling solution. The polished surfaces are rinsed with distilled water and acetone. The electrode probe is then connected to the potentiostat and active surface is immersed in a cell filled with distilled water and maintained at room temperature. The regimes are loosely chosen as to capture different stages of the corrosion.**[28]**
To further understand and to test the corrosion, scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used to characterize samples before and after corrosion testing.XRD scans were carried out using a Smartlab 1 kW powder system equipped with a Cu target. The operational tube voltage and current were 40 kV and 44 mA, respectively. The formed rust powders were collected with a 20-ml glass vial immediately after corrosion testing. After drying, characterization was conducted by SEM and XRD.[29]

## 3. RESULT &DISCUSSION

Welding is a metal joining technique mostly used in fabrication industries for joining of plates and pipes.This literature survey provides information on the loss of material due to the effects of both erosion and corrosion in both high temperature oxidizing and gasifier conditions.

The effects of the steel microstructure on erosion of carbon steels was studied mainly by slurry erosion test. The effect of slurry velocity and concentrations on erosion behavior were discussed. The slurry needs to be changed regularly due to the high flow rate of the abrasive particles. In slurry erosion, large and sharp particles cause more wear than small and rounded particles. Dominant erosion mechanisms were identified by SEM observation. Normalized erosion rate of the steels increases with increasing slurry velocity. The higher particle velocity has higher kinetic energy, which cause more material removal from the matrix. More material removal occurs with increasing slurry concentration. Erosion of ferrite and pearlite is controlled by slurry velocity, solid concentration, impacting particle trajectory and micro structural orientation.

The general methods used in the control of corrosion are coating, cathodic protection, material selection, environmental modification, and design practices. Control of underground corrosion is primarily achieved by two methods: coating and cathodic protection. The formation of a layer of corrosion products which could dramatically decrease the corrosion. Surface morphology SEM studies revealed the presence of a porous solid layer of corrosion products.

## 4. CONCLUSION

This paper provides the overview on erosion and corrosion types, mechanism of erosion and corrosion, mechanical and metallurgical changes occurring when the various grades of steel weldments prone to erosion, corrosion, combined erosion- corrosion in applications such as chemical and processing industries. The erosion and corrosion rate on various materials were primarily categorized and analysed based on the material loss occurring on the surface and the failure type in the application in which it is employed. The SEM images of the eroded and corroded surfaces provide the material modification occurred on the components due to various environmental conditions. Further, this detailed study provides the strong base for conducting the experimental investigations on butt welded A106 Grade-B pipes for analyzing its erosion and corrosion behaviour under acidic and alkaline conditions.

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