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Comparative corrosion study of mild steel in Rajshahi University tap water by immersion test

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ABSTRACT

The corrosion nature of mild steel in Rajshahi University tap water along with distilled water and acid water have been investigated by immersion test and surface analysis. The comparative corrosion rates have been calculated based on the mass loss due to immersion in the medium. In some cases, corrosion has been found to be higher in distilled water than in tap water. It is believed that tap water contains some metal ions that play a special role in preventing corrosion in aqueous medium. Same surface morphologies were observed of specimen immersed in tap water and distilled water. However, numbers of pits and grain boundaries were observed on the specimen immersed in acid water indicated that severe corrosions were occurred. Rajshahi University tap water mostly turbid and contains different ions specially, iron and chloride ions. Due to having some aggressive ions initially corrosion rate is increased then decreased consistently with time for the presence of metal cations. If the water is filtered then some unwanted matters and aggressive ions are removed and corrosion rate also declined a bit. However, this dirty water become useless in the laboratory as well as in the washroom. On the other hand, corrosion rate in distilled water was found to be higher than tap water. Because distilled water is free from aggressive ions as well as metal cations.

1. Introduction

Corrosion is the deterioration and loss of a material and its critical properties due to chemical, electrochemical and other reactions of the exposed material surface with the surrounding environment [1, 2]. Corrosion of metals and nonmetals takes place due to the gradual environmental interaction on the material surface. The structures and facilities of different materials are affected by this interaction. Even the ambient air, laden with moisture and oxygen, can start this process, known as rusting, on steel surfaces. In the case of buried structures and pipelines the soil chemistry and moisture determine the rate of damage. Fumes of acids such as sulfuric acid and dust of caustic soda also accelerate corrosion [3]. In the case of aluminum, however, the oxide film formed due to initial corrosive attack protects the surface from further damage. In marine environments, in which airborne salt crystals are deposited onto ships, corrosion of submerged surfaces as well as surfaces floating above water level occurs. Corrosion affects the microstructure, mechanical properties and the physical appearance of the materials. Rusting and other types of deterioration drastically reduce the capacity of pipelines and equipment, resulting in loss of output as well as loss of equipment, or even life. Hence, anti-corrosive coatings are used to combat the corrosion damage to critical structures and equipment [4]. Corrosion is a dangerous and extremely costly problem. Because of it, buildings and bridges can collapse, oil pipelines break, chemical plants leak, and bathrooms flood. Corroded electrical contacts can cause fires and other problems, corroded medical implants may lead to blood poisoning, and air pollution has caused corrosion damage to works of art around the world. Corrosion threatens the safe disposal of radioactive waste that must be stored in containers for tens of thousands of years.

Mild steel is not an alloy steel and therefore does not contain large amounts of other elements besides iron. Since its carbon and alloying element content are relatively low, there are several properties it has that differentiate it from higher carbon and alloy steels. The negligible amount of alloying elements also helps mild steel to be relatively affordable when compared with other steels. The affordability, weld ability, and machinability that make mild steel such a popular choice of steel for consumers. Therefore, steels are very common materials that are used abundantly and play a major role in our daily and industrial life [1-5]. It is a basic attitude that all metals are chemically unstable in an ordinary environment except noble ones. When metal contacts with environments, chemical reactions are started, and generally metal oxide is formed [6]. For this reason, all non-noble metals tend to form a layer of metal oxide, although this layer is thin (5-10 nm). The oxide layer of metals works as a barrier against the surrounding environment [6]. The stability of oxide films depends on the composition and environmental conditions. **Fig. 1** shows the composition and structure of oxide films in different metals [7-9]. The oxide layer of mild steel (**Fig. 1.a**)) has a poor protection ability, and the layer is damaged, metal dissolution is initiated. Stainless steel contains chromium which provides a unique self-healing property. In case the surface is scratched or damaged, the thin oxide layer formed on the surface (**Fig. 1.b**)), which is only a few nm thick (1~3 nm), immediately rebuilds the layer (oxide film) with the assistance of oxygen from air or water. This is the reason why stainless-steel shows excellent corrosion resistance property compare to the other steels. Therefore, the oxide films on the metal surface play an important role in the properties of metals and have a great influence against corrosion. Aluminum alloy also shows good corrosion resistance due to the stable oxide layer (**Fig. 1.c**)) on the surface.

the surface of the metal, the produced M^{n+} reacts with OH^- to form metal hydroxide as shown in **Eq.** (**4**).

$$M^{n+} + nOH^- \rightarrow M(OH)_n \quad \textbf{(4)}$$

If the amount of hydroxide produced exceeds the solubility, the surface of the metal is covered with the precipitation of hydroxide, and the hydroxide may undergo a dehydration reaction as in the **Eq.** (**5**), oxides are formed.

$$M(OH)_n \rightarrow MO_{n/2} + n/2\ H_2O \quad \textbf{(5)}$$

Therefore, the metal surface is covered with hydroxide or oxide in aqueous solutions[14-16]. Depending on the type of metallic material, oxide films are formed on the metal in the atmosphere or hydroxides are formed in the solution may become a highly protective film. This is generally called oxide films (passive films), and the reason why aluminum, titanium, stainless steel has high corrosion resistance is attributable to these oxide films. Once the oxide films are destroyed [17-23], corrosion starts with the chemical reactions as mentioned in **Eqs.** (1) and (2). Deterioration of the entire exposed surface of a metal by uniform corrosion attack is mentioned as general corrosion [24-30].

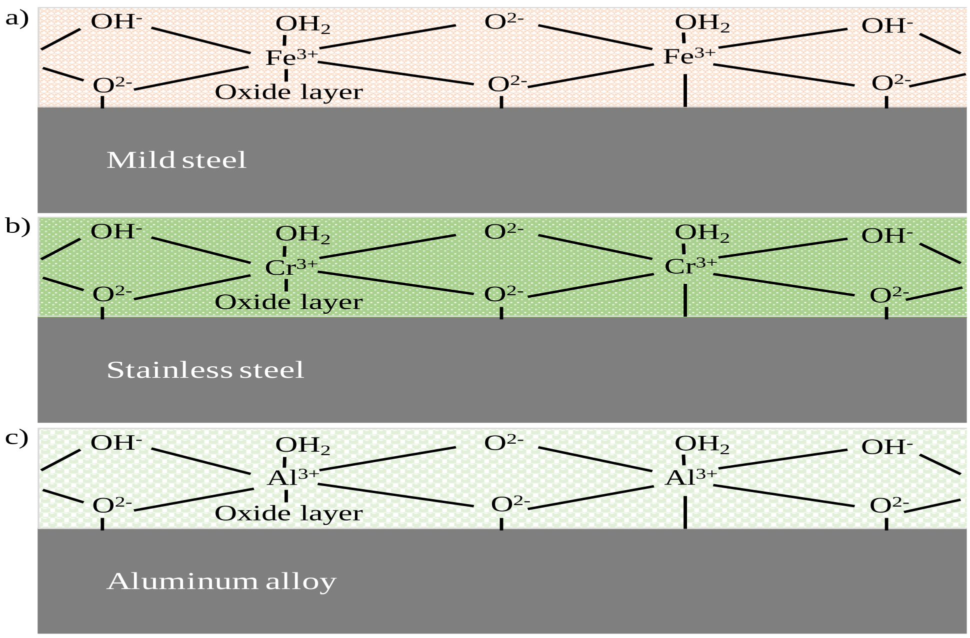

Figure 1 Composition and structure of oxide films in different metals.

Corrosion of metals is a natural phenomenon in which two chemical reactions are always involved [9-15], one is oxidation reaction (anodic reaction) and another is a reduction reaction (cathodic reaction). Depending on the nature of the environment, reactions are as follows:

$$M \rightarrow M^{n+} + ne^- \quad \text{(anodic reaction)} \quad \textbf{(1)}$$

$$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^- \quad \text{(cathodic reaction in neutral medium)} \quad \textbf{(2)}$$

$$2H^+ + 2e^- \rightarrow H_2 \quad \text{(cathodic reaction in acidic medium)} \quad \textbf{(3)}$$

Since the reactions of the **Eqs.** (**1**) and (**2**) occur simultaneously in the neutral solutions containing oxygen at

1.1 Rajshahi University tap water

Rajshahi University laid in northern area of Bangladesh is one the famous higher educational institution in South Asia. 59 departments along with 3 institutes hold the entire campus. In addition to, it has 17 residential halls, 11 for boys & 6 for girls, and a suitable residential area for teachers & officials. As water is very essential requirement in our day-to-day activities Including science laboratories, residential hall & quarter as well as academic building, a large amount of tap water is used to perform the experiment besides with common affairs in the campus. Furthermore, tap water in Rajshahi is not safe for drinking.

Rajshahi University is using so many mild steels pipelines to supply water to the residential hostel along with academic buildings and laboratories. Corrosion is occurred frequently in the pipelines and leakage is observed. Contaminated water is come out from the tap in the laboratory. This embarrassed situation is happened frequently in laboratory and washroom as well. This is because of corroded pipelines. **Fig. 2** shows the contaminated water comes out from the tap of washroom and laboratory. **Fig. 3** shows the tap water condition before and after filtration and typical chemical compositions.

(1) Washroom

(2) Laboratory

Figure 2 Contaminated water comes out from the tap of washroom and laboratory.

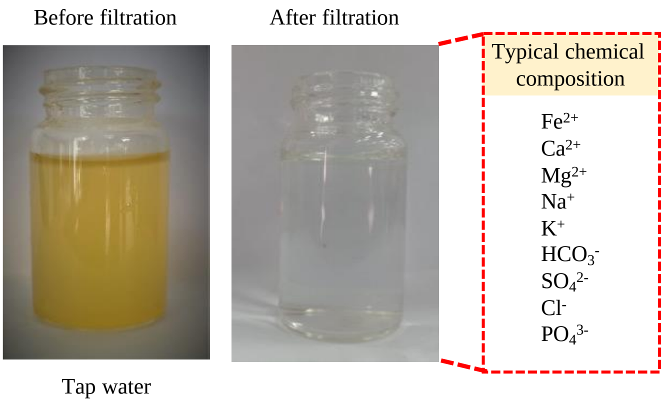

Figure 3 Tap water condition before and after filtration and typical chemical compositions.

1.2 Effect of ions on aqueous corrosion

Tap water contains some ions both positive (Fe^{2+}, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and negative (HCO_3^{-}, SO_4^{2-}, Cl^{-}, PO_4^{3-}) ions. Usually, negative ions destroy the oxide film and accelerate the corrosion of metal [31-36]. Some positive ions have a tendency to form a bond with the oxide film and act as a barrier for the negative ions as well as inhibit the metal oxidation reaction [9, 37-44]. **Fig. 4** shows the effects of ions on corrosion of mild steel in aqueous medium. Huge amount of money is invested to maintenance the pipelines and it include waste of time and manpower. If it is maintained properly according to the water condition based on the mild steels, then maintenance costs will be reduced and it will save also our valuable time as well.

In the present study, the corrosion behaviors of mild steel will be investigated in Rajshahi University tap water by immersion tests and various surface analytical techniques. This study will help to predict the extent as well as nature of corrosion of pipelines and water tanks and also help to guess the corrosion loss per year in Rajshahi University. Surface examinations will be carried out by digital camera, optical microscopy (OM), scanning electron microscopy (SEM). Corrosion rate will be calculated based on the mass loss of specimens due to immersion in the tests solutions. Main objectives are:

- To evaluate the rate of corrosion by immersion test of mild steel in Rajshahi University tap water.
- To compare the corrosion nature of mild steel among tap, distilled & acid water.
- To study the surface morphologies of immersed samples by using digital camera, Optical microscope and SEM.
- To propose some remedial measures.

2. Materials and methods

2.1 Specimen

A mild steel sheet of 0.7 mm thickness was collected from the local market of Rajshahi District of Bangladesh. The sheet was cut into 7×7 mm in size, and were used as the specimen for this experiment. **Table 1** shows the typical chemical composition of mild steel [9, 37-40]. The specimens were abraded by silicon carbide abrasive paper from #400 to #2000 grit size. **Fig. 5** shows the mild steel specimen after abrasion. Then the specimen was cleaned ultrasonically in ethanol and in distilled water for five minutes. After that the specimens were kept in a desiccator to avoid moisture and contamination until the immersion tests. **Fig. 6** shows the specimen kept in desiccator.

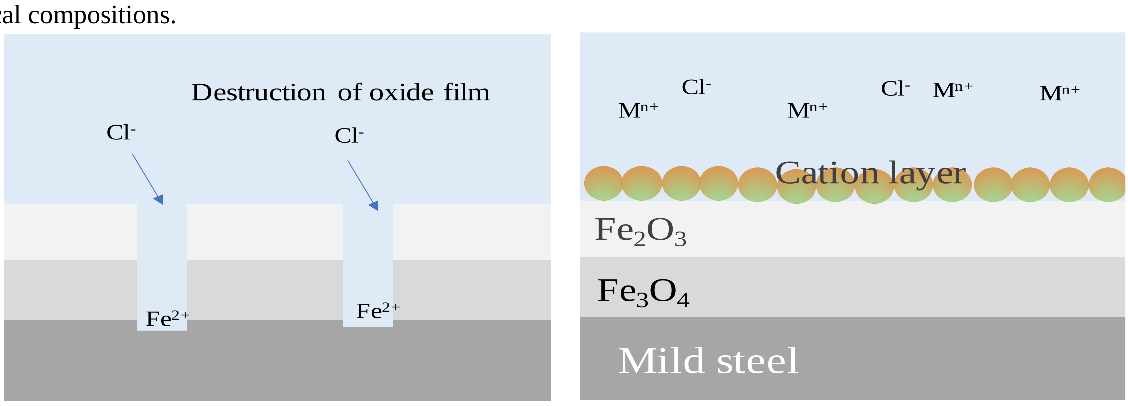

Figure 4 Effects of ions on corrosion of mild steel in aqueous medium.

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Table 1 Typical chemical composition of mild steel (mass %)

C	Si	Mn	P	S	Fe
0.020~ 0.075	0.010~ 0.014	0.180~ 0.200	0.009~ 0.015	0.007~ 0.010	Bal.

Where, M_1 is mass before immersion (mg), M_2 is mass after immersion (mg), D is density of specimen (g/cm^3), S is surface area of specimen (cm^2) and t is immersion time (s).

Table 2 Recorded pH of the testing mediums before and after the immersion tests

SL No.	Mediums	pH before immersion tests	pH after immersion tests			
			12 h	1 d	2 d	3 d
1	DW	7.96 ± 0.11	7.81 ± 0.01	7.63 ± 0.10	7.51 ± 0.21	7.71 ± 0.01
2	TW	7.69 ± 0.15	8.39 ± 0.21	8.19 ± 0.01	8.71 ± 0.02	8.69 ± 0.12
3	AW	-	-	-	-	-

Figure 5 Mild steel specimen after abrasion.

2.2 Test mediums

Three testing mediums were selected for this comparative experiment. Distilled water (DW), Rajshahi University tap water (TW), and 1N HCl (AW) were used as the testing mediums. Tap water of Rajshahi University was collected and filtered to avoid unwanted particles in the medium. The distilled water was used as the reference medium in this experiment. The pH of the mediums was recorded by a pH meter (HANNA) before the immersion tests. All of the mediums were clear and transparent before the immersion tests.

2.3 Immersion tests

The immersion tests were carried out for the several periods of time as 12, 24, 48 and 72 hrs. at 25°C. The pH of the mediums was recorded by a pH meter after the immersion tests. The corrosion rates were calculated based on the mass loss due to immersion in the mediums by using the following **Eq. 6.**

$$\text{Corrosion rate } (\mu m/y) = \frac{(M_1 - M_2)}{D \times S \times t} \times 3650 \qquad (6)$$

2.4 Surface investigations

Surface morphology is the important criteria which reflects the corrosion behavior of the mild steel regarding the medium. Surface observation of specimen after immersion were carried out to clarify the variance of the specified corrosion behavior of mild steel in the different medium. Before and after the immersion tests, the surfaces of the specimens were observed by a digital camera, optical microscope and scanning electron microscope (SEM). The center area of the specimens after immersion was analyzed by XPS using a monochrome Al Kα X-ray source. The diameter of the specimen analyzed by the XPS was 3 mm. Before the surface investigation, the immersed specimens were cleaned in an ultrasonic bath by ethanol and highly purified water. The cleaned specimens were kept in a desiccator to avoid humidity and any type of contamination until surface examinations.

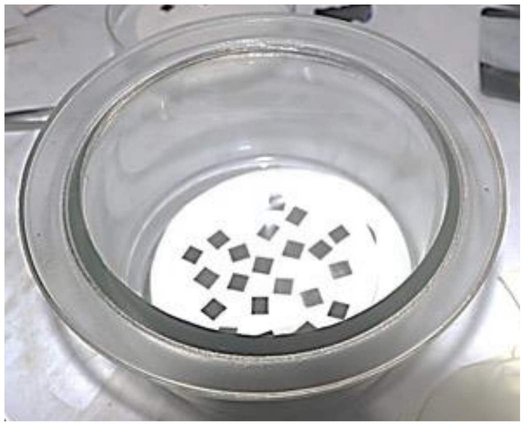

Figure 6 Mild steel specimen kept in a desiccator to avoid contamination.

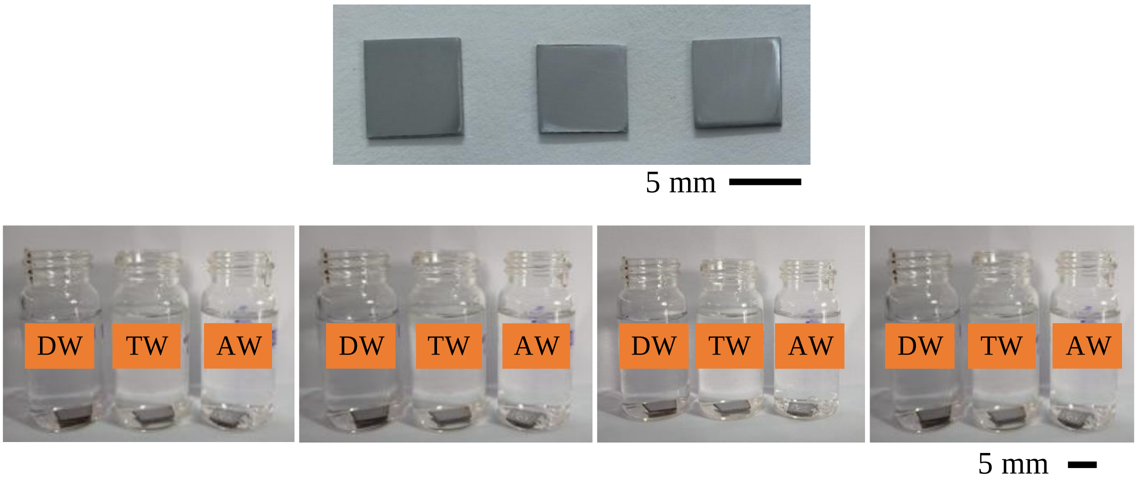

Figure 7 Appearance of specimens and solutions at the starting time of immersion.

3. Results and discussions

3.1 Immersion tests

The immersion tests were carried out for the several periods of time as 12, 24, 48 and 72 hrs. at 25°C. **Fig. 7** shows the appearance of specimens and solutions at the starting of immersion tests.

deposited on the specimen surface that were observed before ultrasonic cleaning, and the amount was varied depending on the solutions and immersion times. After the immersion tests, each specimen was cleaned by ultrasonic cleaner in ethanol and distilled water. Corrosion rate was calculated based on the mass loss due to the immersion in the different mediums. **Fig. 9** shows the corrosion rate with time. Rajshahi University tap water mostly turbid and contains different ions

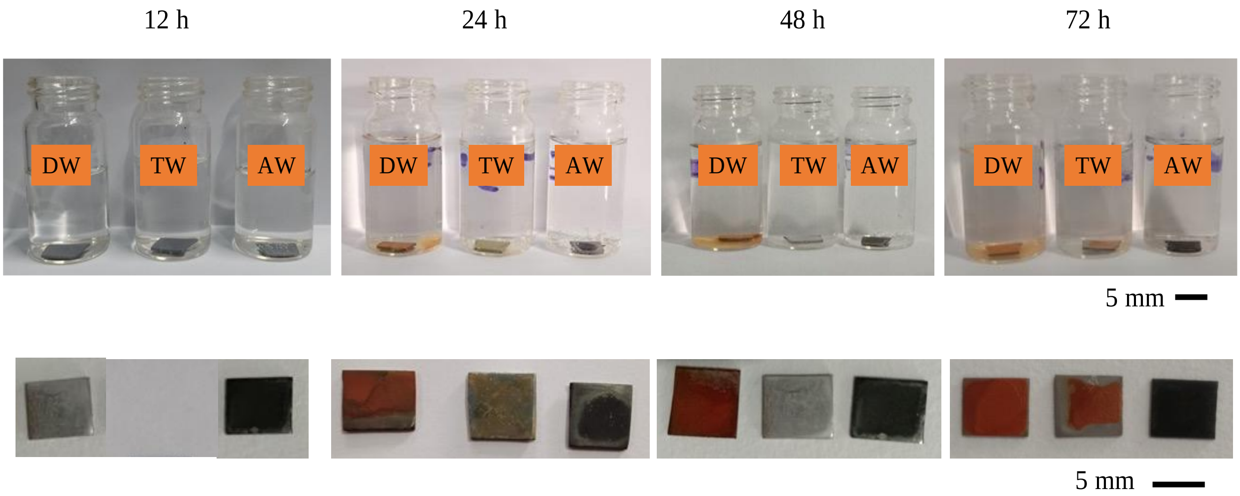

Figure 8 Appearance of solutions and specimens after the immersion period.

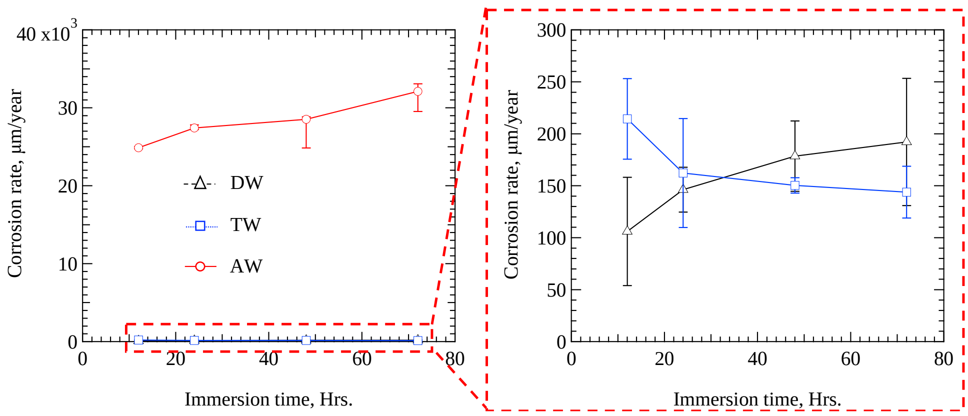

Figure 9 Corrosion rate of mild steel in different medium with time.

Fig. 8 shows the appearance of specimens and solutions after the immersion tests. Brown color corrosion products were

specially, iron and chloride ions. Due to having some aggressive ions initially corrosion rate is increased then decreased consistently with time for the presence of metal cations. If the water is filtered then some unwanted matters and aggressive ions are removed and corrosion rate also declined a bit. However, this dirty water become useless in the laboratory as well as in the washroom. On the other hand, corrosion rate in distilled water was found to be higher than tap water. Because distilled water is free from aggressive ions. **Table 2** shows the recorded pH of the mediums used in this experiment. The pH was slightly increased after immersion in all solutions due to the formation of OH^- at the metal surface [9, 37-44].

3.2 Surface Investigations

The results of immersion corrosion tests showed that the corrosion rates of the specimens after immersion was different in each solution. The changes in the appearance of specimen surfaces were observed to clarify the situation. Specimen surface was first observed by digital camera and then optical microscope, and grain boundaries were observed. To be clearer about surface changes, observations were carried out by SEM. **Fig. 10** shows the optical microscopic images of specimen surface and quite different surface morphologies are observed for the different solutions.

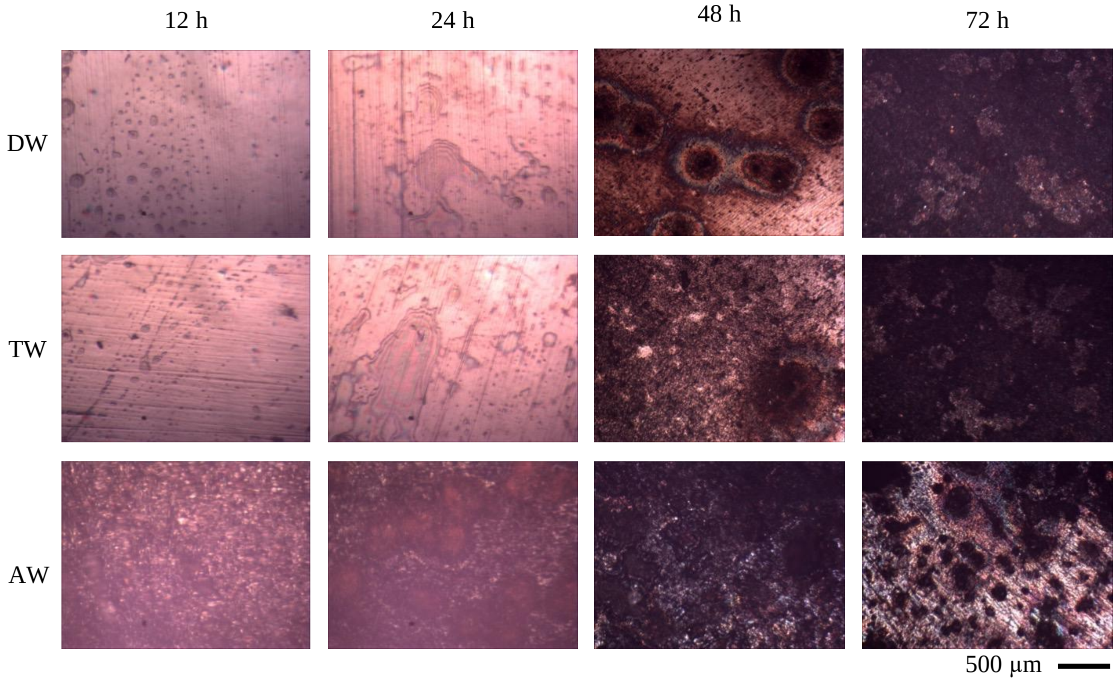

Figure 10 optical microscopic images of specimen surface after the immersion tests at 25°C.

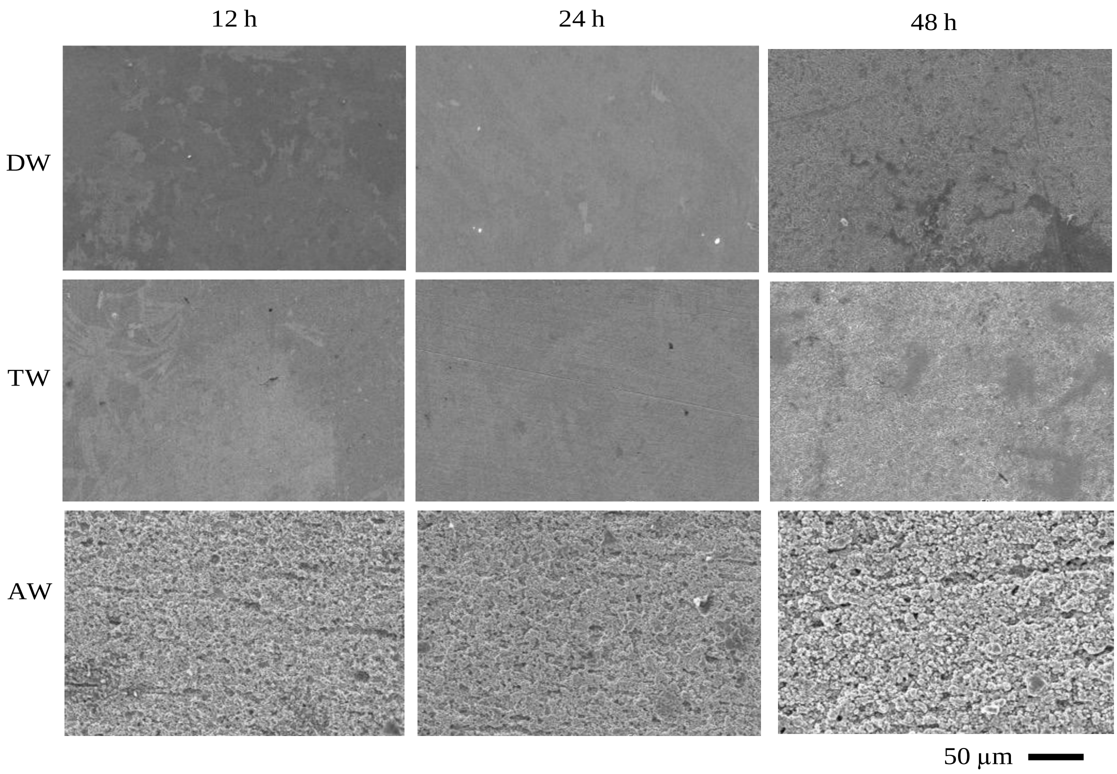

Figure 11 SEM images of specimen surface after the immersion tests at 25°C.

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Several pits and grain boundaries are observed on the specimens immersed in the acid water. Some pirs are also observed on the specimen immersed in the distilled water and tap water.

Fig. 11 shows the SEM images of specimen surface after the immersion tests at 25°C.
Surface SEM images clearly show the number of pits and grain boundaries in the case of specimens immersed in acid water. Small numbers of pits are observed on the specimen immersed in the tap water for 48 h as compared to the specimen immersed in distilled water. The immersion corrosion rate (**Fig. 9**) supports this surface morphological change.
Fig. 12 shows the XPS broad scan spectra of specimen surface after the immersion tests at 25°C. There are no significant differences among the spectrum. In all of the cases Fe2p3/2, C1s, Si2p, Mg2p3/2, O1s peaks are observed.

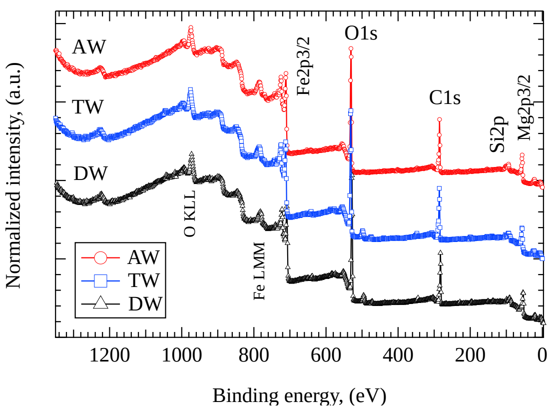

Figure 12 XPS broad scan spectra of specimen surface after the immersion tests at 25°C.

Conclusions

a) The corrosion behaviour of mild steel was observed in the medium of distilled water, Rajshahi University tap water & acid water respectively.
b) Immersion test results showed the different corrosion rate in different water with time.
c) Generally acid water showed high corrosion rate than others.
d) Initially tap water showed more corrosion rate than distilled water because of having some aggressive anions (Cl^-, SO_4^{2-}) in tap water.
e) Corrosion rate in tap water was decreased with time as compared to the distilled water. Because tap water contains some metal cations that have significant corrosion inhibition property.
f) The surface morphologies showed severe corrosion rate with time in acid water as well as distilled water as compared to the tap water.

Recommendations

a) Rajshahi University tap water mostly turbid and contains different ions specially, iron and chloride ions. Due to having some aggressive ions and dirt matters, initially corrosion rate is increased.
b) Though the corrosion rate is decreased with time due to having some metal cations, the corroded and turbid tap water becomes useless in laboratories as well as in the washrooms.
c) If the water is filtered then some unwanted matters and aggressive ions are removed and corrosion rate also declined a bit.
d) It is suggested that central water filtration process can be installed or PVC pipelines and fittings can be used instead of metal pipelines throughout the Rajshahi University to reduce the corrosion.
e) These simple steps may save time, money and manpower as well.

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