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EFFECT OF CORROSION ON MECHANICAL PROPERTIES OF MEDIUM CARBON STEEL IN DIFFERENT SELECTED MEDIA

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Abstract: *This study is to determine the corrosion penetration rate (CPR) of medium carbon steel in selected media and also to analysed the effect of corrosion on the mechanical properties on the steel material. Weight loss experiment was used to determine the corrosion rate and tensile test to conduct the mechanical properties, Ultimate tensile test (UTS), Engineering fracture stress (EFS), Ductility and Yield stress (YS). The study was investigated for a total period of 35days with measurements made at interval of seven days (7), the media used for the research are 0.5mold^{-3}(H_2SO_4), 0.5mold^{-3} (HCL), Freshwater, Air and Soil. The result showed that medium carbon steel has a very high failure tendency in acidic media than in the other media. The tensile test result at the end of the analysis showed that there was a great deterioration in the mechanical properties in air as the ultimate tensile test stress, engineering fracture stress and ductility which were initially 830.130N/mm^2,112.,435 N/mm^2 and 14.50% before corrosion experienced a decrease in value to 733.38 N/mm^2, 830.019 N/mm^2 and 10.714% respectively. Therefore, we can conclude that medium carbon steel is an unreliable constructional material in H_2SO_4 acid and HCL acid environment due to the effect on their mechanical properties*

Key words: *Medium Carbon Steel, Corrosion Penetration Rate, Weight Loss, Corrosion Media, Mechanical Properties, Environment*

INTRODUCTION

Carbon steel is one in which the alloying element is carbon, the percentage of carbon content in the steel composition determines the strength and hardness. Therefore, carbon steel can be classified as low, medium and high carbon steel. Lindberg, (2018) states that carbon steel with carbon content between 0.3-0.6 percent is termed medium carbon steel while those with less than 0.3% and greater than 0.6% are classified as mild and high carbon steel respectively. Mild, medium or high carbon steel materials are majorly used in modern industries for construction of equipment and plant facilities. These equipment and plant facilities are exposed to outdoor conditions often in highly polluted atmospheres where corrosion is considerably more severe. Most of these environments are acidic in nature which brings about the deterioration of engineering structures, and consequent failure if not carefully handled. Due to the growing application of steel in the industries and for economic purposes, there is a need to regularly ascertain the corrosion characteristics of materials being used in these industries.

This helps in determining the most appropriate corrosion control and preventive strategy, thereby enabling the engineer to know the best environment suitable for the location of an industry. The end result would be durability of engineering facilities even after a long period of time. Medium carbon steel is a key engineering material for construction. Though it possesses some good mechanical properties such as strength, hardness etc., its major problem of corrosion has been a great challenge to manufacturers. Over the years, efforts are being made to curb these challenges, to give manufacturers some great deal of confidence when using this material. A review of literatures reveals that most of the current research focuses on corrosion rate, corrosion penetration and corrosion mechanism.

In acidic environment, Oluwole *et al.,* (2013) investigated the corrosion characteristics of electroplated medium carbon steel in sodium carbonate environment for decorative object application. The result obtained showed that plated medium carbon steel generally had a better corrosion resistance than the unplated one. This is an evidence that plated medium carbon are reliable materials for decorative object application in sodium carbonate environment. Okuma *et al.,* (2020) also studied the corrosion behaviour of mild steel in some selected media (H_2SO_4, HCL, Underground soil and Freshwater). Weight loss method was used to determine the corrosion behaviour of mild steel in the media. The result obtained showed that mild steel exhibited fast corrosion rate at the early stage of the exposure period to the different media. However, as the exposure period was prolonged, there was a continuous decrease in the corrosion rate among the media. H_2S0_4 showed more aggressiveness in terms of corrosion and weight loss when compared to HCL, Underground soil and Fresh water environment. Ajide *et al.,* (2012) research work in acidic environment was limited to determination of corrosion penetration rate on the medium carbon steel without stating how this corrosion rate would affect the mechanical properties of the steel which would eventually lead to failure. This paper investigates the effect of corrosion on the mechanical properties of medium carbon steel material in the selected environment.

MATERIAL AND METHODS

2.1 Material Selection and Testing

The samples of medium carbon steel material used for this study were obtained from Premium Steel and Mines Ltd, formally, Delta Steel Company, Aladja, Delta State, Nigeria. The composition of the material and mechanical properties was conducted as shown in Table 1 and Table 2.

Table-1 Chemical Composition of Medium Carbon Steel Sample

C	Si	Mn	P	S	Cr	Ni	Mo	Al
0.63	0.198	0.82	0.005	0.018	0.060	0.089	0.0088	0.0013
Cu	Co	Ti	Nb	V	W	Pb	B	Sn
0.136	0.0077	0.0022	0.0062	0.0014	0.0010	0.011	0.0014	0.0064
Zn	As	Bi	Ca	Ce	Zr	La	Fe	
0.0025	0.0013	0.0008	0.0011	0.0058	0.0058	0.0006	98.0	

A. Tensile Test before Corrosion

Initial Length=28mm; Initial Diameter=5mm; Initial Area=19.635mm^2

Final Length=32.062mm; Final Diameter=4.3mm; Final Area=14.522mm^2

Max. Load = 16300N

Fracture Load=16300N

Yield Load=13600N

Max. Extension (dl)= 4.062mm

Table-2 Tensile Test

Forces(N)	2000	4000	6000	8000	10000	12000	14000	16000
Stress(N/mm^2)	101.86	203.72	305.58	407.44	509.22	611.15	713.01	814.87
Extension(mm)	0.375	0.812	1.187	1.437	1.812	2.187	2.687	3.812
Strain	0.013	0.029	0.042	0.051	0.064	0.078	0.095	0.136

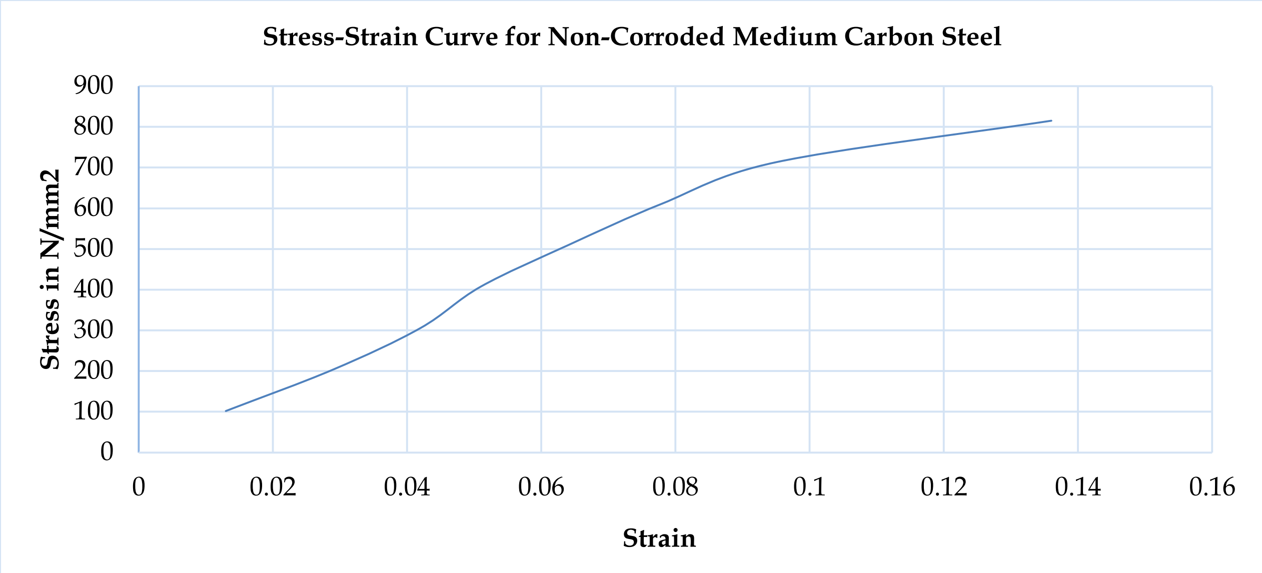

Fig 1 Stress-strain curve for non-corroded medium carbon steel

2.2 Test Media for Corrosion Analysis

The following media were used for the analysis, Sulphuric acid (H_2SO_4) with concentration of 0.5moldm^3, Hydrochloric acid (HCL) 0.5moldm^{-3}, Freshwater, Soil and Air.The choice of selection of these media is based on their applications and the use of these materials in the industrial sector such as manufacturing, oil and gas industries. These industries use construction materials for the storage tank of some substances and also for the construction of pipelines and vessels which are used to transport substances from one point to the other.

2.3 Shape and Size of Samples

The samples used in the study are coupons of medium carbon steel rods with diameter 20mm and length 60mm

Length=60mm=6cm

Diameter=15mm=1.5cm

Surface Area, A= $2\pi r^2+2\pi rL$

$A = 2\times 2 \times \frac{22}{7} \times (0.75)^2 + 2\times\frac{22}{7} \times 0.75 \times 6 = 31.83cm^2$

Density= $\frac{Mass}{Volume}$

Volume of cylinder=$\pi r^2 h=\frac{22}{7} \times (0.75)^2 \times 6 = 10.61cm^3$

Density =$\frac{70}{10.6} = 6.604g/cm^3$

2.4 Preparation of Samples for the Determination of the Corrosion Penetration Rate

After all the surface preparation process, acetone was used to wash off the grease before immersion. Rope was tied around the samples for the purpose of suspending it so that it does not rest directly on the container. Five of the samples were tied to one stick which was immersed into each of the test media.

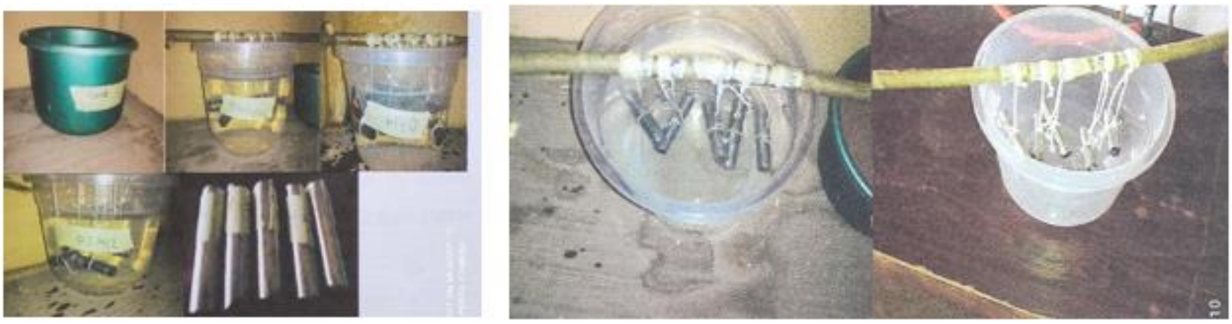

Fig 2 Samples in Test Media

2.5 Determination of the Corrosion Penetration Rate

Twenty-five (25) samples of medium carbon steel rods were used for the weight loss and corrosion rate experiments. The initial weight of each piece was measured with a weighing balance and recorded (all coupon have equal weight). Five coupons were immersed into each of the test media for a total period of thirty-five (35) days. At the end of seven (7) days, one of the samples is removed from each of the media, after which it is washed and re-weighed. The loss in weight of the samples is calculated, the corrosion penetration rate is determined by the use of equation (1) below (ASTM 2003).

$$CPR\ (mm/yr.) = 8.76\times10^{4}\times W/AT\rho \quad (1)$$

where;

CPR= Corrosion penetration rate (mm/yr.)

W= Weight loss in g

ρ =Density in g/cm^3

A= Exposed total surface area in cm^2

T= Time of exposure in hours

RESULTS AND DISCUSSION

3.1 Corrosion Penetration Analysis

The Corrosion penetration rate of medium carbon steel in the different media for a period of 5 weeks (35days) were calculated and tabulated as shown in Table 3.

Table-3 Corrosion Penetration Rate

S/N	Media	Week1	Week2	Week3	Week4	Week5
1	H_2SO_4	44.18	23.75	15.92	12.04	9.83
2	HCL	31.04	16.02	11.02	8.52	7.02
3	Freshwater	21.61	9.94	7.54	5.65	4.78
4	Air	20.11	11.06	5.69	5.53	4.42
5	Soil	21.61	11.12	7.58	5.81	4.78

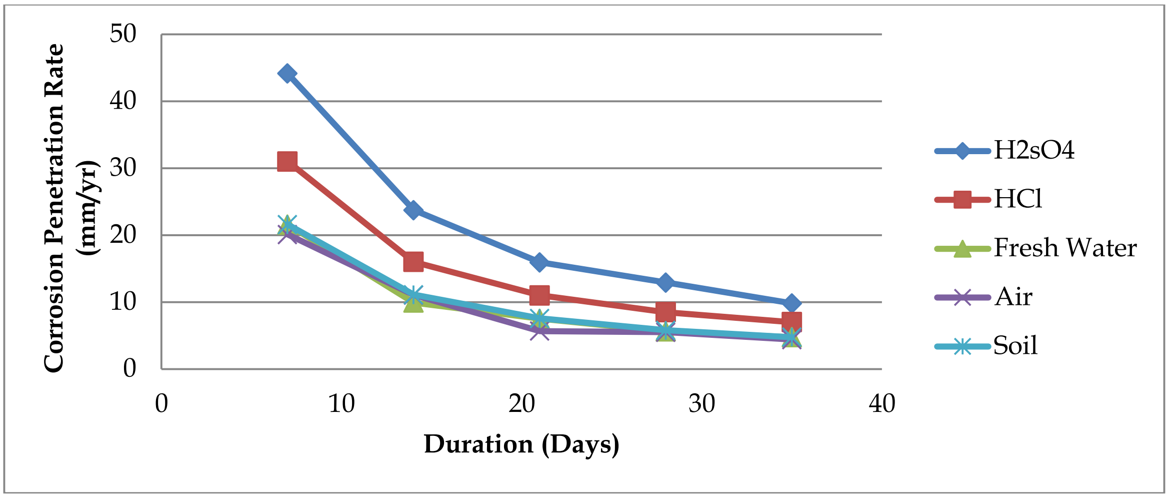

Fig.3 Comparison of corrosion penetration rate in the different media

As seen in Fig. 3 above, H_2S0_4 had the highest penetration rate. It is also observed that medium carbon steel exhibited the same deterioration behaviour in all media, that is, a gradual decrease in value of the corrosion rate penetration. The behaviour of the sample could be attributed to infant mortality, where a material suffers high deterioration rate at the early stage of its life (as seen in the graph between the first 14 days). As time increases, the deterioration rate reduces and becomes a little stable between the 14^{th} to the 35^{th} day. This period is referred to as the useful life of the material, after some period of usage the rate of deterioration picks up again, this is referred to as wear period.

3.2 Effect of Corrosion on the Mechanical Properties of the Medium Carbon Steel at the end of the Analysis

A. Tensile Test Result Interpretation for Air-Corroded Medium Carbon Steel

Initial Length=28mm; Initial Diameter=5mm; Initial Area=19.635mm^2
Final Length=31mm; Final Diameter=4.7mm; Final Area=17.349mm^2
Max. Load = 14400N
Fracture Load=14400N
Yield Load=13600N
Max. Extension (dL) = 3mm

Table-4 Tensile Test Result for Air-corroded Medium Carbon Steel

Forces (N)	2000	4000	6000	8000	10000	12000	14000
Stress (N/mm^2)	101.86	203.72	305.58	407.44	509.29	611.15	713.01
Extension (mm)	0.437	0.875	1.125	1.437	1.812	2.187	2.750
Strain	0.016	0.031	0.040	0.051	0.065	0.078	0.098

The Ultimate Tensile Stress (UTS): $\frac{144000}{19.635}$= 733.384N/mm^2
The Engineering Fracture Stress (EFS): $\frac{144000}{17.349}$ = 830.019N/mm^2
The Ductility: $\frac{3}{28} \times 100 = 10.714\%$
The Yield Stress (YS): $\frac{136000}{19.635}$ = 692.641 N/mm^2

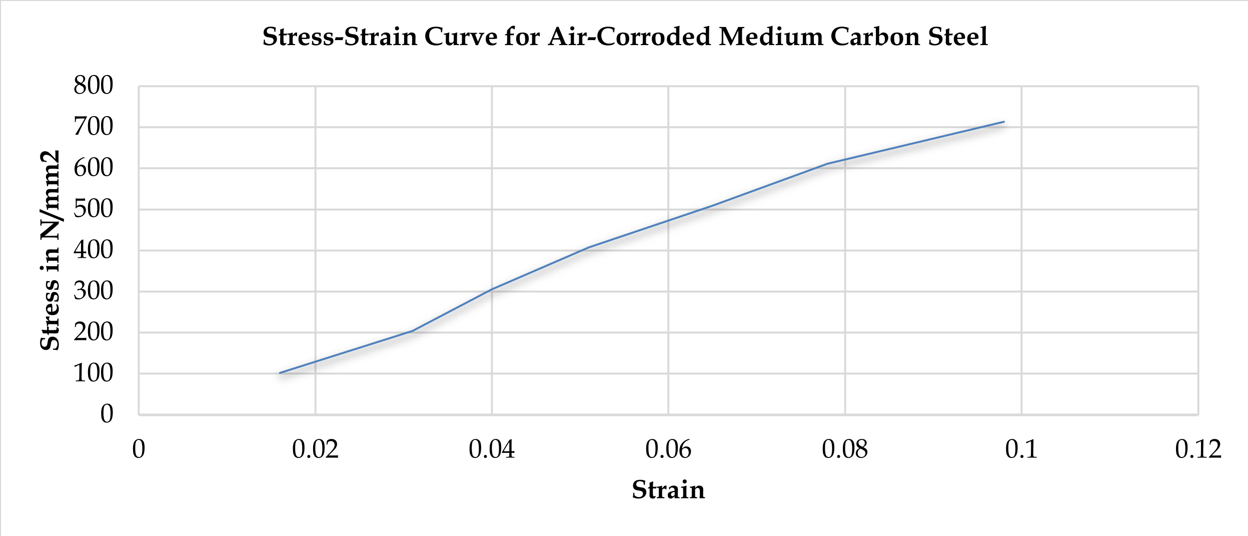

Fig. 4 Stress-strain curve for air-corroded medium carbon steel

B. Tensile Test Result Interpretation for Soil-Corroded Medium Carbon Steel

Initial Length=28mm; Initial Diameter=5mm; Initial Area=19.635mm^2
Final Length=32.812mm; Final Diameter=3.8mm; Final Area=17.341mm^2
Max. Load = 15500N
Fracture Load=14200N
Yield Load=13600N
Max. Extension (dL) = 4.812mm

Table-5 Tensile Test Result for Soil Corroded Medium Carbon Steel

Forces (N)	2000	4000	6000	8000	10000	12000	14000
Stress (N/mm^2)	101.86	203.72	305.58	407.44	509.29	611.15	713.01
Extension (mm)	0.315	0.719	1.062	1.375	1.750	2.125	2.750
Strain	0.013	0.026	0.038	0.049	0.062	0.076	0.098

The Ultimate Tensile Stress (UTS): $\frac{155000}{19.635}$= 789.407N/mm^2
The Engineering Fracture Stress (EFS): $\frac{142000}{11.341}$ = 1252.20N/mm^2
The Ductility: $\frac{4.812}{28} \times 100 = 17.186\%$
The Yield Stress (YS): $\frac{136000}{19.635}$ = 692.641 N/mm^2

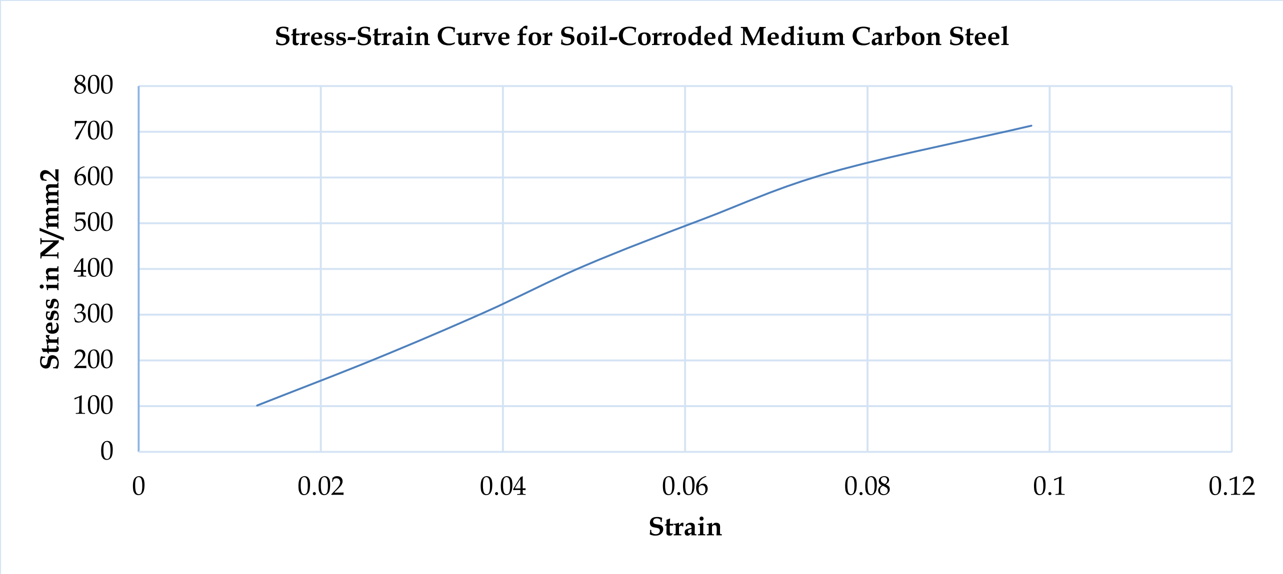

Fig. 5 Stress-Strain curve for Soil-corroded Medium Carbon Steel

C. Tensile Test Result Interpretation for Freshwater-corroded Medium Carbon Steel

Initial Length=28mm; Initial Diameter=5mm; Initial Area=19.635mm^2
Final Length=32.625mm; Final Diameter=4.5mm; Final Area=15.904mm^2
Max. Load = 167000N
Fracture Load=16700N
Yield Load=15000N
Max. Extension (dL)= 3.625mm

Table-6 Tensile Test Result for Freshwater-Corroded Medium Carbon Steel

Forces (N)	2000	4000	6000	8000	10000	12000	14000	16000
Stress (N/mm^2)	101.86	203.72	305.58	407.44	509.29	611.15	713.01	814.87
Extension (mm)	0.315	0.719	1.062	1.375	1.750	2.125	2.750	3.250
Strain	0.013	0.026	0.038	0.049	0.062	0.076	0.098	0.116

The Ultimate Tensile Stress (UTS): $\frac{16700}{19.635}$= 850.522N/mm^2
The Engineering Fracture Stress (EFS): $\frac{16700}{15.904}$ = 1050.050N/mm^2
The Ductility: $\frac{3.625}{28} \times 100 = 12.946\%$
The Yield Stress (YS): $\frac{136000}{19.635}$ = 692.641 N/mm^2

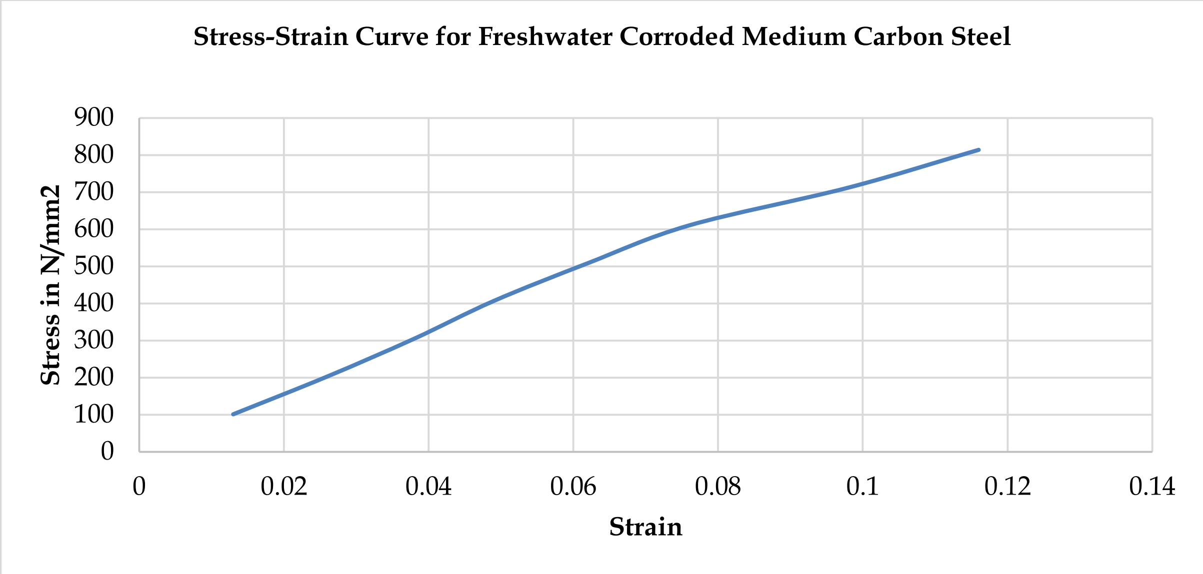

Fig. 6 stress-strain curve for freshwater-corroded Medium Carbon Steel

D. Tensile Test Result Interpretation for H_2SO_4 corroded Medium Carbon Steel

Initial Length=28mm; Initial Diameter=5mm; Initial Area=19.635mm^2
Final Length=32.00mm; Final Diameter=4.4mm; Final Area=15.205mm^2
Max. Load = 167000N
Fracture Load=17100N
Yield Load=13600N
Max. Extension (dL) = 4mm

Table-7 Tensile Test Result for H_2SO_4 Corroded Medium Carbon Steel

Forces (N)	2000	4000	6000	8000	10000	12000	14000	16000
Stress (N/mm^2)	101.86	203.72	305.58	407.44	509.29	611.15	713.01	814.87
Extension (mm)	0.469	0.875	1.812	1.500	1.750	2.125	2.562	3.187
Strain	0.017	0.031	0.065	0.054	0.062	0.076	0.091	0.114

The Ultimate Tensile Stress (UTS): $\frac{17100}{19.635}$= 870.894N/mm^2
The Engineering Fracture Stress (EFS): $\frac{17100}{15.904}$ = 1124.630N/mm^2
The Ductility: $\frac{4}{28} \times 100 = 14.286\%$
The Yield Stress (YS): $\frac{136000}{19.635} = 692.641$ N/mm^2

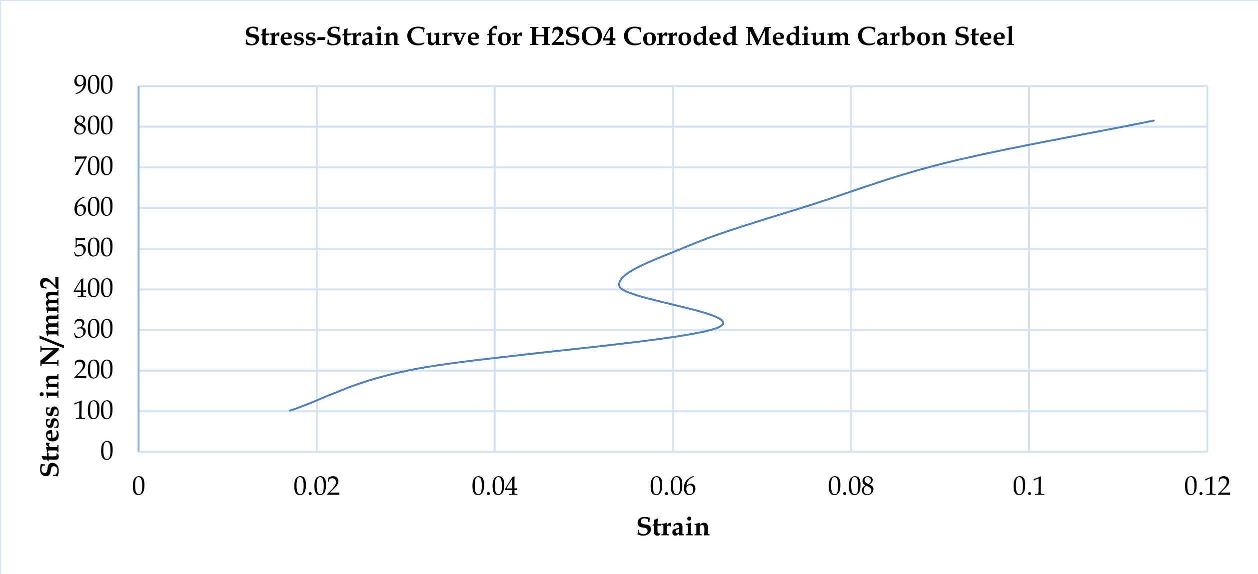

Fig.7 stress-strain curve for H_2SO_4 corroded Medium Carbon Steel

E Tensile Test Result Interpretation for HCL corroded Medium Carbon Steel

Initial Length=28mm; Initial Diameter=5mm; Initial Area=19.635mm^2
Final Length=32.437mm; Final Diameter=4.4mm; Final Area=15.205mm^2
Max. Load = 15600N
Fracture Load=15600N
Yield Load=13600N
Max. Extension (dL) = 4.437mm

Table-8 Tensile Test Result for HCL Corroded Medium Carbon Steel

Forces (N)	2000	4000	6000	8000	10000	12000	14000
Stress (N/mm^2)	101.86	203.72	305.58	407.44	509.29	611.15	713.01
Extension (mm)	0.625	1.00	1.375	1.684	2.00	2.437	3.062
Strain	0.022	0.036	0.049	0.060	0.714	0.087	0.109

The Ultimate Tensile Stress (UTS): $\frac{15600}{19.635}$= 794.499N/mm^2
The Engineering Fracture Stress (EFS): $\frac{15600}{15.904}$ = 1025.98N/mm^2
The Ductility: $\frac{4.437}{28} \times 100 = 15.848\%$
The Yield Stress (YS): $\frac{136000}{19.635}$ = 692.641 N/mm^2

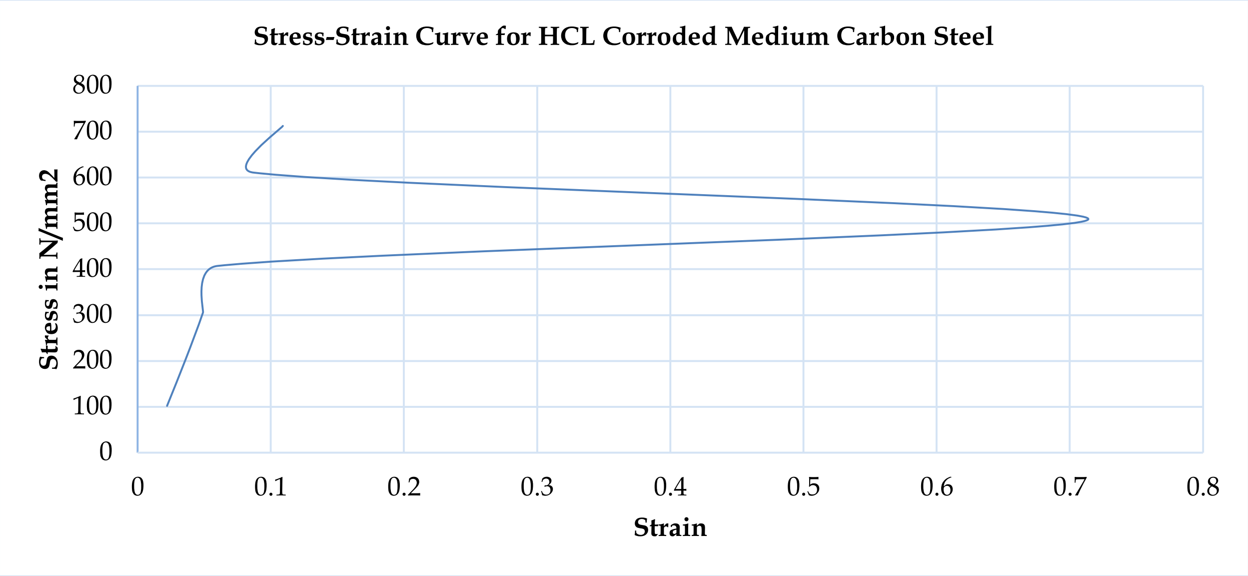

Fig. 8 Stress-strain curve for HCL corroded Medium Carbon Steel

RESULTS AND DISCUSSION

Fig. 2 gives a description of the corrosion comparison analysis of medium carbon steel in the different media (H_2SO_4, HCL, Freshwater, Air and Soil). The corrosion penetration rates (CPR) of steel in H_2SO_4 was 0.4418×10^2mm/yr. at the end of the first 7th days. At the 14th day, there was sharp decrease in the corrosion penetration rate to 0.2375×10^2mm/yr., this is an indication that corrosion deterioration continued throughout the period of the experiment. Similar behavioural pattern was observed in the other media (HCL, Freshwater, Air and Soil). These corrosion behaviours of the material deterioration in these media are high. This is an evidence to show that medium carbon steel is not a reliable constructional material in any acidic environment as the rate of deterioration could result to early failure of the facility.

Analyses of the tensile test carried out on the steel material to determine some properties such as the Ultimate tensile test (UTS), Engineering fracture stress (EFS), Ductility and Yield stress (YS). 830.150N/mm^2, 1122.435N/mm^2, 14.50%, and 692.64N/mm^2 are the original values for the UTS, EFS, Ductility and YS respectively. Results of another test conducted on the corroded steel from all the media at the end of the 35 days showed significant changes in their properties. The yield strength remained unchanged; the air media corroded steel witnessed greater reduction in these properties. The UTS, EFS, and Ductility reduced to 733.384 N/mm^2, 830.019 N/mm^2 and 10.714% respectively. These results imply that medium carbon steel in air became more brittle and can fracture easily, even though the corrosion penetration rate was low. Fracture could still occur due to the changes in mechanical properties as shown in figures 4 to 8. Figures 4 to 8 show the stress-strain curve of the corroded material in the different media and how they varied from the initial curve (figure 1) before they were corroded in the various media.

CONCLUSION

The results from the study show that medium carbon steel is an unreliable alloy in the fabrication of machinery and tools for processing H_2SO_4 and HCL and also not suitable in environments where these media are present as contaminants; this is due to the high rate of corrosion penetration and material deterioration. From the material test conducted it can be concluded that the environment which this material is exposed to tend to affect its mechanical properties in term of decrease in the ultimate tensile stress, engineering fracture stress and its ductility.

However, if need arises to use medium carbon steel without inhibitor; then Freshwater, Air and Soil are preferable over the acidic media, as their corrosion penetration rates and material deterioration are lower.

RECOMMENDATION

Considering the rate of corrosion penetration in the different media, it is recommended that when using medium carbon steel as constructional material, inhibitor should be used to reduce the rate of corrosion penetration and material deterioration. This inhibitor would also improve the useful life of machinery. In the construction industry, it is recommended that a model be created to determine the useful life of material used for fabricating machines.

CONFLICT OF INTEREST

This research work was carried out by me and there is no conflict of interested associated with it.

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