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Corrosion Properties of Plain Carbon Steels

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ABSTRACT

This paper looks at the corrosion characteristics of two grades of plain carbon steels of Ajaokuta steel company limited, namely, DIN 35-2 (Ribbed rod) and DIN 37-2 (plain rod). In three environments: Salt solution, Tap water and Moist soil. The company is located in Northern Nigeria. The corrosion characteristics of these two grades of plain carbon steel were studied under cold work condition and as rolled or untreated condition in the aforementioned media for a period of 22 days. Result obtained show that corrosion rates increases with increasing degree of cold work. In addition, it was found that corrosion rates of these products vary in the different corroding media with moist soil having the highest corrosive ability, followed by tap water and then 3% by weight of sodium chloride salt solution. Also the rib rod samples essentially corroded more than the plain rod samples in these various environments.

***Keywords*:** *Corrosion, Plain Carbon Steels, Cold work,*

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I. INTRODUCTION

Corrosion is recognized as a major problem both in developed and developing nations of the world. Millions of naira are being spent every year to control tosses of corrosion. With the added interest of steel technology and steel production in Nigeria, it is of paramount importace that thorough studies and investigations be carried out to estimate how these steel products behave in use. In this respect, their corrosion properties are of paramount importance.

This paper looks at the corrosion properties of steels produced by Ajaokuta Steel company limited in different corroding environments namely: tap water, moist soil and 3% by weight of sodium chloride solution. Three percent of sodium chloride was used because its corrosive ability had been studied and known. Also salt solution stimulates the natural sea water in the laboratory because sea water in the laboratory does not truly represent the natural environment. This is also a consequence of the changes that occur in it on storage. Majorly the research will dwell on the two common known steels:

1) Plain carbon steel
2) Alloy steels (UHLIG+, H.H. 1963)

Experiment is carried out on plain carbon steel because they are the most common sued steels in the industries. Plain carbon steels are divided into three groups:

1) low carbon steel
2) medium carbon steel
3) high carbon steels

Steel – Carbon Steel

It is an alloy of iron and carbon, with carbon content up to maximum of 1.5 – 2.0%. The carbon occurs in the form of iron carbide, because of its ability to increase the hardness and strength of the steel. Other certain elements like silicon, phosphorus, sulphur and manganese are also present in greater or lesser amount to impart certain amount of desirable properties to it. Most of the steels produced recently is the plain carbon steel or carbon steel. A carbon steel is defined as a steel which has its properties mainly due to its carbon content and does not contain more than 0.5% of silicon and 1.5% of manganese. (R.S Khurmi, J.K. Gupta 2005) (DEUTCHMAN, A.D. et al 1975). The plain steels are usually classified in their carbon content, the commonest of the range being mild steel carbon content. (W.A.J. Champion 1972).

APPLICATIONS OF CARBON STEELS (Chapman 1985)

CARBON %	USES
Dead mild 0.1-0.125	Wire rod, thin sheets, solid drawn tubes, etc
Mild (low) 0.15-0.3	Boiler plates, bridge work, structural sections, drop forgings, general workshop purposes.
0.3-0.5 (0.05% - 0.30)	Axes, drop forging, high tensile tubes and wire agricultural tools.
Medium carbon (0.5 – 0.7)	Springs, locomotive tyres, large forging dies, wire ropes, hammers and snaps for riveters.
0.7 – 0.9 (0.3% - 0.5%)	Springs, small forging dies, spear blades, cold setts, wood chisels.
High carbon (0.9-1.1)	Cold chisels, press dies, punches, secrewing dies, wood working tools axes, picks.
1.1 – 1.4 (0.50% - 2.0%)	Razors, hand files, drills,gauges, metal-cutting tools.

This research paper is expected to help us understand how steel products of Ajaokuta Steel company and other related steel products corrode in different environments. It will also assist in finding means of minimizing or even preventing corrosion for it is said that “an ounce of prevention is worth a pound a pound of cure”. Or better say “prevention is better than cure”.

Plain Carbon Steel

The two types of carbon steels are plain carbon steel and alloy steel. Plain carbon steel is one which contains in addition to carbon and iron certain elements notably manganese, phosphorus, supphur and silicon in small quantities. It may also contain traces of elements like: copper, boron, cobalt and so on.
Plain carbon steel is divided into three groups:

1) low carbon steel
2) medium carbon steel
3) high carbon steel

(YOUNG, J.F.1982 Materials and Processes).

Hot And Cold Working Of Plain Carbon Steel

Rolling , forging, drawing, compression and extrusion and typical methods by which metals are worked especially steels have great effects on their mechanical and metallurgical properties. Cold working refers to the act of permanently deforming a cold metal. The term cold is relative. Even room temperature may be hot for such metals i.e as lead. A metal is said to be cold when it is worked at a temperature below recrystallization temperature but below the melting or boiling point is termed hot working. Metals are subjected to mechanical working for two general purposes:

a) To reduce the original block or slug of metal approximately to the finished dimension of the part or mill form, thereby saving material, machining cost and time.
b) To improve the mechanical properties of the material thoroughly

Definition of Corrosion

Corrosion may be defined broadly as the destruction or deterioration of metal by direct chemical and electro-chemical reaction with its environment. Most simply stated, metallic corrosion is the reverse of electroplating. The metal being corroded forms the anode while the cathode is that being electroplated. Metallic corrosion occurs because in many environment most metals are not inherently stable and tend to revert to some more stable combination of which the metallic ores as found in nature are familiar examples.

Factors Influencing Corrosion Of Plain Carbon Steels

Generally, the factors affecting the rate of corrosion of plain carbon steels are either material dependent or environment-dependent or a combination of both . Some of the factors which are associated mainly with metals are:

1) Over voltage of metal on the hydrogen.
2) Chemical and physical homogeneity of the metal surface.
3) Inherent ability to form an insoluble protective film
4) Hydrogen ion Activity (PH) in the solution
5) Influence of oxygen in the solution adjancent to the metal
6) Rate of flow of solution in contact with metal

Significance of Corrosion

Corrosion has a lot of significance economically, socially and otherwise. This led J.M. West to write, "Corrosion kills people, waste resources and cost money we can ill afford". But except for a few corrosion reactions which are of practical importance for example, the corrosion of metallic lead, the effects of corrosion are nothing to write home about.

Some of the disadvantage of corrosion includes:

(a) Wastage of material, money, time and man power due to over design, because of corrosion.
(b) Contamination of products eg damage of entire batch of soap by a corroded copper
(c) Cost of replacing corroded structure or components
(d) Loss of products for example oil or gas losses in corroded pipes.

II. METHODOLOGY

In this chapter, the focus includes methods and techniques adopted as well as the materials used for this study. This contains material used, working samples adopted and relevant carbon test carried out.

III. DESCRIPTION

Ajaokuta steel company limited was visited and some relevant materials were obtained for the study from this company. The material gotten from the company is Plain Carbon steel in the form of 16mm plain rolled rods (steel grade: DIN 37-2) and 16mm ribbed rods (DIN 35-2). These rods were subsequently reduced to the required dimensions for the experiment using the lathe machine, grinding machine and hack saw. The diagram below shows reduction procedure adopted using the lathe machine.

Mounting steel/rod on a lathe machine for reduction process

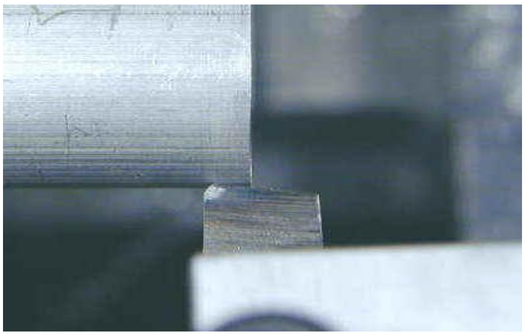
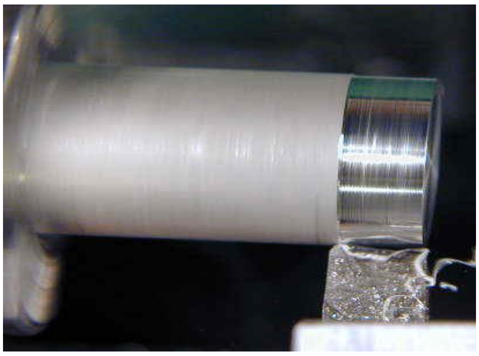


Fig 3.2: Reduction process of steel/rod on a Lathe Machine



After machining the materials they were further polished and cleaned with emery paper.The ribbed rods were reduced to 10mm in diameter and 20mm by length, this was done to ensure that ribs were completely removed for easier calculation of the exposed surface areas of the specimens. Then the plain rolled rods were reduced to 13mm in diameter and 20mm in length. All these measurements were done using the vernier callipers. These diameters were chosen in this manner wit diameter of samples being about one-half the length, to enable us compress the sample without them experiencing buckling effects. Specimens produced were 108: 56 plain rolled rod and 56 ribbed rod.

Cold Working Of Samples

Coldworking of samples was achieved by compression. The compressive behaviours of each of the two different materials was determined using the 40-ion universal testing machine (UTM) in the laboratory. The testing was done to determine the different degrees of compression to which the material could be subjected without necessarily crushing them.

18 specimens of the ribbed rod were subjected to a compressive load of 7000kgf which compressed the length from 20mm to 17.8mm and enlarged the diameter from 10mm to 10.6mm. Also 18 more specimens of the ribbed rod were subjected to a compressive load of 7500kfg reducing the length of each of the 18 specimens from 20mm to approximately 15.7mm with diameter enlarged to 11.29mm. The percentage of cold work in the above two cases were calculated as follows:

$$\% \text{ cold work } (\%CW) = \frac{\text{Change in cross-sectional area}}{\text{Original corss-sectional area}}$$

%CW : 1 = 12.36%
%CW : 2 = 27.5%

Similarly, 18 plain rolled samples were given about 16% cold work by subjecting them to a compressive load of 7500kgf which compressed each of them from a length of 26mm to 22.4mm and increased their diameter approximately from 13mm to 1.401mm. In addition, 18 more samples of plain rolled rod were subjected to 9000kgf(compressive load) which gave about 30% cold work to each of them by reducing their length from 13mm to 1.482mm.

Corrosion Tests

Preparation Of Corroding Media

Three types of corroding media were used, namely

1) Tap water – a sufficient quantity of weight 890 per bowl was used. The quantity was large enough for complete immersion of the corrosion specimen.
2) Moist soil – sandy loam soil of the following properties was used: PH value in H20=4.2, in Kcl=3.7
3) NACL solution – 3% by weight of NACL solution was used. The solution coomprised of distilled water and common salt(NaCl), mass of distilled water used per bowl was 790g. using the electronic weighing balance, mass of NaCl was 24.432g

Corrosion Of Samples

Eighteen plastic bowls were provied for eighteen groups of sample products. Specimens were weighed with electronic weighing balance, wih exposed surface area calculated. The compressed samples were again measured to determine the changes in lengths with new diameters calculated. The samples were arranged in three subscripts i.e tap water, salt solution and moist soil respectively. Care was taken not to allow samples to touch one another in order not to initiate galvanic action. As corrosion of samples proceeded day after day, distilled water was added to the salt solution or tap water solution to make up for losses due to evaporation. Decrease in the moisture conent was noticed by occasionally filling and reweighing the bowls to determine the loss in weight.

Determination of Weight Lost

No corrosion of sample was noticed the first day, corrosion was noticed the third day and care was taken to remove only the corrosion products. The samples were weighed with electronic weighing balance to determine their new weights. The weight loss of each of the samples was determined and recorded. The process of washing,drying,weighing,deterination of weight loss and recording was repeated for the 6th, 10th, 14th, 18th, 22nd days.

Experimental Results And Analysis

The lengths, diameter and surface areas for the three groups of each of the two grades of plain carbon steel namely DIN 35-2(ribbed rod) and DIN37-2(plain rod) are given in the tables of three samples (As Rolled Samples ARS; Compressed Samples with 1st degree of cold work CDW1 and Compressed samples with second degree of cold work CDW2) below:

Table 4.1 TYPICAL INITIAL PARAMETERS for Ribbed Rod (Din 35-2) Samples

Group	Diameter,D (cm)	Length,L (cm)	Total Surface Area(cm2)
ARS	1.000	2.00	7.8540
CDW1	1.060	1.78	7.6925
CDW2	1.129	1.57	7.5708

Table 4.2 TYPICAL INITIAL PARAMETERS for Plain Rod (DIN37-2) Samples

Group	Diameter,D (cm)	Length,L (cm)	Total Surface Area(cm2)
ARS	1.300	2.60	13.2732
CDW1	1.400	2.24	12.9422
CDW2	1.482	2.00	12.7617

Table 4.3 As Rolled Samples(ARS), Group 1 Material: Ribbed Rod Medium: Tap Water

DAYS	SAMPLES	INITIAL WEIGHT (kg)	WEIGHT LOSS (mg)	EXPOSED SURFACE AREA(CM2)	WEIGHT LOSS/SURFACE AREA(mg/cm2)
0	A	12.110	0	7.854	0.0000
3	B	12.115	4	7.854	0.5093
6	C	11.987	13	7.854	1.6552
10	D	12.105	24	7.854	3.0558
14	E	12.082	32	7.854	4.0743
18	F	11.985	37	7.854	4.7109
22	G	12.110	53	7.854	6.7482

Table 4.4 Compressed Samples (CDW1), Group 2 Material: Ribbed Rod Medium: Tapwater

DAYS	SAMPLES	INITIAL WEIGHT (kg)	WEIGHT LOSS (mg)	EXPOSED SURFACE AREA(CM2)	WEIGHT LOSS/SURFACE AREA(mg/cm2)
0	H	12.154	0	7.6925	0.0000
3	I	11.943	12	7.6925	1.5600
6	J	12.148	19	7.6925	2.4699
10	K	12.001	28	7.6925	3.6399
14	L	12.110	37	7.6925	4.8271
18	M	12.010	48	7.6925	6.2398
22	N	12.154	57	7.6925	7.4098

Table 4.5 Further Compressed Samples (CDW2), Group 3 Material: Ribbed Rod Medium: Tapwater

DAYS	SAMPLES	INITIAL WEIGHT (kg)	WEIGHT LOSS (mg)	EXPOSED SURFACE AREA(CM2)	WEIGHT LOSS/SURFACE AREA(mg/cm2)
0	O	12.000	0	7.5708	0.0000
3	P	11.997	13	7. 5708	1.7171
6	Q	12.090	22	7. 5708	2.9059
10	R	12.011	32	7. 5708	4.2267
14	S	11.989	41	7. 5708	5.4155
18	T	12.003	50	7. 5708	6.6043
22	U	12.000	60	7. 5708	7.9252

Table 4.6 As Rolled Samples(ARS), Group 4 Material: Ribbed Rod Medium: NaCl Solution

DAYS	SAMPLES	INITIAL WEIGHT (kg)	WEIGHT LOSS (mg)	EXPOSED SURFACE AREA(CM2)	WEIGHT LOSS/SURFACE AREA(mg/cm2)
0	A2	12.103	0	7.854	0.0000
3	B2	12.002	3	7.854	0.3819
6	C2	12.000	9	7.854	1.1459
10	D2	11.998	18	7.854	2.2918
14	E2	12.100	28	7.854	3.5651
18	F2	11.993	33	7.854	4.2017
22	G2	12.103	37	7.854	4.7110

Table 4.7 Compressed Samples (CDW1), Group 5 Material: Ribbed Rod Medium: NaCl Solution

DAYS	SAMPLES	INITIAL WEIGHT (kg)	WEIGHT LOSS (mg)	EXPOSED SURFACE AREA(CM2)	WEIGHT LOSS/SURFACE AREA(mg/cm2)
0	H2	12.101	0	7.6925	0.0000
3	I2	12.237	7	7.6925	0.0100
6	J2	11.990	10	7.6925	1.3000
10	K2	11.989	19	7.6925	2.4699
14	L2	12.001	29	7.6925	3.7699
18	M2	12.121	38	7.6925	4.9399
22	N2	12.101	43	7.6925	5.5899

Table 4.8 Further Compressed Samples (CDW2), Group 6 Material: Ribbed Rod Medium: NaCl Solution

DAYS	SAMPLES	INITIAL WEIGHT (kg)	WEIGHT LOSS (mg)	EXPOSED SURFACE AREA(CM2)	WEIGHT LOSS/SURFACE AREA(mg/cm2)
0	O2	12.172	0	7.5708	0.0000
3	P2	11.987	8	7. 5708	1.0567
6	Q2	11.998	13	7. 5708	1.7171
10	R2	12.003	21	7. 5708	2.7738
14	S2	11.997	31	7. 5708	4.0947
18	T2	12.013	40	7. 5708	5.2835
22	U2	12.172	46	7. 5708	6.0760

IV. OBSERVATION

After the first day, each samples were surrounded by yellowish deposits evident in the tap water than salt solution. As days progress the deposits turned brown identified to be ferric hydroxide. Some shiny white patches of particles were suspected to be ferrous hydroxide formed due to the presence of insufficient oxygen. On withdrawal of specimed immersed in the moist soil, dark brown deposits of ferric hydroxide were noticed on them.

The corroding media (tap water and salt solution) were observed to decrease continuously in volume due to evaporation of water. The decrease in the volume of media was evident from the ringed marks on the bowl inducating the original levels of the media. On washing of sample from salt solution and tap water, it was observed that the deposit on them were relatively easily removed except for the dark patches of samples which took quite some time, but samples of moist soil were not easily washed off.

Analysis Of Result

Based on the results deduced from the table, the analysis of result shows that on the whole, the ARS have the lowest corrosion rate, followed by CDW1 and the CDW2 having the highest corrosion rate. If a graph is plotted , the as rolled samples curve (ARS) will follow a gradual increase in corrosion attack on the first 6 days and then increase suddenly 4 days after followed by a gradual increase in the next 8 days and another increase in the last 4 days. Curves CDW1 and CDW2, has relatively high corrosion on the first 6 days. On the whole, the as rolled samples have the lowest corrosion rate , followed by CDW1 and with the CDW2 having the highest corrosion rate. Sudden change in the rate of corrosion attacks of the metals mentioned could be associated with the physical breakdown of the barrier films of the corrosion products which encourages corrosion attacks by exposing new surface area of the metals.

In the case of moist soils the changes could be explained by the effect of making up of moisture loss which tends to promote corrosion. The marked low corrosion rates in the initial days mentioned especially for as rolled samples might be attributed to the effect of the surface finish of the samples. The as rolled samples have better surface finish of the samples. The as rolled samples have etter surface finish than the compressed samples. On the other hand the low corrosion rates experienced as the corrosion progressed after many days are likely indications that the protective films (corrosion products) accumulated over the past days tend to lower the rates of corrosion attack by not allowing enough contact between samples and corroding media.

The general trend obtained whereby the compressed samples corroded higher than their corresponding as rolled samples might be as a result of the increased rate of dissolution of the higher energy (strained) grains produced by the cold work effect by the corroding media. The fact that the samples coldworked to a higher degree corroded more than that cold worked to a lesser degree indicated that the increased rate of dissolution of the high energy (strained) grains is highest for them.

V. CONCLUSION

In general, the rate of corrosion of plain carbon steels is dependent on both the environmental conditions, structural and compositional properties of the steel. Within the limits of experimental error, conclusions drawn based on observations and result of the research are:

1) In corroding media for example, NaCl solution, tap water and moist soil , corrosion of plain carbon steel depends on the amount of oxygen dissolved in the media.
2) Among the three corroding media used in the experiment, moist soil has the highest corrosive ability followed by tap water and then NaCl solution.
3) The degree of cold water increases the corrosion of plain carbon steels of Ajaokuta steel company limited.
4) Plain carbon steels of Ajaokuta steel company limited as comparable to its counerparts from other places.

Suggestions For Future Work

a) To eliminate or reduce errors in future investigations of corrosion properties of materials by weght lost per unit area method, the following are sugested:
b) The use of a better means of removing adherent corrosion products, say by the use of chemical means.
c) An open building with the roof covered for better air circulation than the present laboratory should be provided for the experiment to allow better free circulation of air and real atmospheric condition to play their natural parts in corrosion process without rain necessarily disrupting the project set up.
d) It is suggested that future researchers wishing to investigate properties of materials formulate mathematical relations existing between the extent of corrosio attack and time as well as investigation of corrosion properties of other steel products of Ajaokuta steel company limited and other local steel producing companies.

Limitations Of Experimental Results

The possible sources of errors are likely to be from:

1) The instument used: such errors include errors due to low sensitivity of instruments, faulty instruments etc
2) The method of preparing the samples by machining , grinding and cleaning with energy paper may not have ensured uniform surface finish and dimensions where necessary. Also in the compression process, the stress developed in the process may not have been uniformly distriuted.
3) The physical method of removing corrosion products can introduce errors, since the corrosion product may not be properly and completely removed.
4) The atmospheric condition that obtains in the laboratory may not compare favourably with that obtained in a better open place. Hence free circulation of air and real atmospheric conditions may not be allowed to play their natural part in the corrosion well enough.

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