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Effect of Surface Finish on Corrosion and Microstructure of Carbon Steel-(C-1020) and Stainless Steel-(SS304)

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Abstract*— The article is on experimental studies of the effect of surface finish on the corrosion rate and microstructure of Low Carbon Steel (C-1020) and Austenitic Stainless Steel (SS304). The method was based on conducting Linear Polarization Resistance Test and Metallography experiment on six metal samples to determine the rate of corrosion and changes in microstructure respectively. The six metal samples included three (C-1020) and three (SS304). The experiment involved the use of equipment such as, Oxford Instrument X-MET 7500 Spectrometer, MITECH Hardness Tester, Mould (Punch and dye), Hydraulic Press, Emery paper, and MS1000 Instrument. Diluted Hydrochloric acid was used as the corrosion medium. The metal samples were polished with emery papers of 220, 320 and 800 grits and then immersed in six beakers containing 25ml of the corrosion media each. After every interval of five minutes, the instantaneous corrosion rate value was read from the MS1000 instrument for forty minutes Linear Polarization Resistance test revealed that (C-1020) with surface roughness of 0.935 microns had the highest rate of corrosion and (SS304) with surface roughness of 0.271 had the lowest rate of corrosion. Thus for (C-1020) and (SS304) the rate of corrosion is directly proportional to the surface roughness. The metallography test revealed that metals have weaker resistance to failure after linear polarization test. These results have a wide applicability; better material selection in oil and gas pipelines which are highly sensitive to corrosion, storage tanks where corrosion is inevitable and offshore platforms.*

Keywords*— Surface finish, Corrosion rate, Microstructure, Carbon steel, Stainless steel.*

NOMENCLATURE

Abbreviation	Meaning
C-1020	Plain Carbon Steel (PCS)
SS304	Austenitic Stainless Steel (SS)
D	Density
LPR	Linear Polarization
ZRA	Zero Resistance Ammeter
Cr2C	Chromium Carbide
W	Weight
NaCl	Sodium Chloride
H_2SO_4	Sodium tetra-oxo Sulphate (vi)
Ti	Titanium
Cr	Chromium
Mn	Manganese
Fe	Iron
Zn	Zinc
Si	Silicon

I. INTRODUCTION

Corrosion is a point of interest to multi-disciplinary research groups incorporating knowledge from metallurgy, material science, physics and chemistry [1, 2]. In an effort to understand the mechanisms of corrosion, the reactions at the interfaces between the corrosive electrolyte and the steel surface, specifically at the initial stages of the corrosion process needs to be described [3]. Corrosion is the breakdown of materials due to chemical reactions as a result of oxidization with air molecules, usually in the presence of water [4]. It also occurs when an acidic or basic material comes in contact with another material [5]. Surface roughness, which often characterizes the physical and mechanical factors affecting metals, is a major influence on general corrosion and microstructure of metals [6]. Microstructure refers to the arrangement of atoms in an ordered, repeating, and three dimensional patterns. Metals are common elements used in almost all engineering works. However, most metals have the tendency to return to their oxide state (natural state) with adverse changes in the properties through time thus resulting in economic waste and loss [7]. More literatures have been carried out in this area and include: Deepak et al. [8], brought to attention the importance of surface features of carbon steels, such as texture and surface energy, along with defects dislocation related to mechanical processing of carbon steels [4]; Suber et al. [9], found out that shear stress reduction leads to less shear texture formation and resulted in disappearance of gross and brass texture in corrosion wear situation due to NaCl acting as a lubricant and reducing frictional force; Makarenko et al. [10], observed that the steel with fiber texture developed through warm texture offered good resistance against hydrogen induced corrosion, whereas random texture caused hydrogen induced corrosion; inter granular stress corrosion cracking depend on texture and grain boundary. High angle grain boundaries are prone to corrosion but sometimes cracks might be arrested at high angle grain boundaries [11]. Lu et al. [12], revealed that corrosion rate of cold steel was higher than the hot rolled steel under aggressive corrosion environment (16.9vol% H_2SO_4 and 0.35vol% HCl at 60°C, pH 0.3), when comparing the properties of the steels formed by hot and cold rolling; Jason et al. [13], revealed that surface roughness slightly increased while micro-hardness showed

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higher values after pickling treatment; Mirjam et al. [14], showed that surface roughness affects the growth of the passive layer in urban rain significantly although the growth of such films is retarded in case of the NaCl aqueous solution; Mohammad and Ahmed, [15], in influence of heat treatment and surface finish on the behaviour of crevice corrosion resistance of AISI 410 and 416 martensitic stainless steels, showed that corrosion resistance decreases when hardness and surface roughness increases; and in inter-granular corrosion, attack usually progresses along the grain boundary in a narrow path, for a severe case of grain boundary corrosion; entire grains may be dislodged due to complete deterioration of their boundaries [3].

The end result of surface finish on the microstructure and corrosion behaviour of C-1020 and SS304 is thus carried through: determination of the chemical composition of the samples, the effect of different grades of surface finish on the microstructure, effect of the change in microstructure on the corrosion rate of C-1020 and SS304 in an acid (HCl) environment using linear polarization method. Corrosion is an inevitable phenomenon but it has caused many complications, expensive due to loss of materials or their properties and leads to loss of time during maintenance, the shutting down of systems and severe failure of some structures. This article provides a direction for predicting the possible reaction and type of corrosion that would occur in Stainless steel – SS304 [Austenitic Stainless steel] and Carbon steel – C-1020 [Low carbon steel] under certain conditions and circumstances which will aid in material selection and optimal application of material.

II. Material and Methods

2.1 Materials

The equipment and apparatus used for measuring the effect of surface finish on Microstructure, corrosion of low carbon steel (C-1020), and Austenitic stainless steel (SS304) [16] are: MS 1000 corrosion meter; MITECH Hardness Tester (MH310); Surface Roughness Tester SRT 6100; Oxford instrument XMET 7500 XRF spectrometer; PTS Inverted Metallurgical Microscope; EP-302 Electrolytic Polisher and Etcher; Hacksaw; Sand Paper; and Coupons (Stainless and low Carbon Steels) of 12 pieces each of sizes 40mm x 20mm x 4 mm.

2.2 Methods

Materials for microstructure determination are;

2.2.1 Coupon Preparations

The material for the coupon was made of stainless and low carbon steels of sizes 480 x 240 x 4mm which were purchased from steel market at Oyigbo town, in Oyigbo local Government Area of Rivers State. The Austenitic Stainless and low Carbon Steels were then cut into pieces of sample size of 40mm x 20mm x 4mm each. The 24 pieces of the Coupons for both steels were thoroughly sand papered to get different grades of surface finish, that is, 120, 400, and 1200 of grit numbers to get three (3) different roughness surfaces for the austenitic stainless and low Carbon Steels. 120 grit numbers represent the rougher finish while 1200 grit is the most polished surface for both steels.

2.2.2 Sample Characterization

Oxford instrument (X- MET 7500 spectrometer) was used to determine the composition of the stainless and plain carbon steels. The samples for both steels were taken into the TURRET Engineering service limited for the test on the analysis of the chemical composition of the materials. The essence of this test was to determine the characteristics of the various steels and their identification.

2.2.3 Chemical Analysis of Metal

Chemical analysis determines the composition of the material under investigation. Characterization was done using ‘Oxford instrument X-MET 7500 Spectrometer’ in order to discover the composition of the metal. The characterization test was performed in *Turret Engineering Laboratory* and the results shown in Tables 1 and 2.

TABLE 1. Positive Material Identification Report for Stainless Steel

CLASS	ALLOY LE-FP									
GRADES	SS321 (0.43), SS304 (O.60)									
ELEMENTS	Si%	Ti%	Cr%	Mn%	Fe%	Co%	Ni%	Cu%	Nb%	Mo%
+/-	1.44	0.08	17.41	1.90	69.27	0.34	8.99	0.17	0.01	0.39
	0.105	0.022	0.116	0.094	0.256	0.038	0.103	0.018	0.004	0.010

TABLE 2. Positive Material Identification Report for Low Carbon Steel

CLASS	ALLOY LE-FPM					
GRADES	C-1020 (0.00), C-1026 (0.32)					
ELEMENTS	Si%	Ti%	Cr%	Mn%	Fe%	Zn%
+/-	1.86	0.30	0.04	0.37	97.37	0.05
	0.117	0.025	0.009	0.021	0.242	0.012

2.2.4. Hardness Test

The hardness test conducted was the *LEEBS HARDNESS TEST*. Hardness tester (MH 310) was used to carry out this test to evaluate a material’s property such as strength, ductility, and wear resistance and also, to determine whether a material or material treatment is suitable for the desired purpose. Coupon was placed upon a block where the tester was used to strike at 3 different points on the coupon surface and values recorded on averagely. This test was carried out before and after the corrosion test [17].

2.2.5. Metallography

The structures observed in the microscope are often recorded photographically. The surface of a metallographic specimen is prepared by various methods of grinding, polishing and etching. After preparation, it is often analysed using optical or electron microscopy. Using only metallographic techniques,

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alloys can be identified and material properties can be predicted. Mechanical preparation is the most common preparation method. Successively finer abrasive particles are used to remove material from the sample surface until the desired surface quality is achieved. Metallographic specimens are mounted using a hot compression thermosetting resin; the specimen is wet ground to reveal the surface of the metal. A diamond grit suspension which is dosed onto a reusable fabric pad is employed throughout the polishing process. Etching is the next step taken to reveal the microstructure of the metal through selective chemical attack. It also removes the thin, highly deformed layer introduced during grinding and polishing. Finally, the microstructure of the specimen is studied with a microscope and can be recorded photographically. Metallography is carried out before and after linear polarization resistance test to study the changes in the microstructure due to the effect of surface finish and corrosion [18]. The metallography experiment was done in the materials laboratory, Federal University of Technology, Owerri, Imo State, Nigeria.

2.2.6. Surface Finish Testing

This test is essential because it is use to determine the Microstructure of the steels. The sample piece (three different grades of grit numbers 120, 400, 1200) was placed in the middle of the mould and the unoccupied spaced in the mould was filled with thermosetting materials (phenolic powder) [12, 16, 19]. A pressure of 3mN (0.003N) was applied using hydraulic pressure and then the mould was placed inside the heater before it was switched on. The set-up was allowed until indicator light on the heater trips off and thus the specimen was finally ejected from the mould. The surface of the specimen (collected from the sampled coupon using the mould) was grinded on series of adhesive papers of grades 220 microns, 400 microns, 600 microns and 800 microns until a smooth surface was achieved. The polishing was carried out in a machine using velvet cloth, diamond paste and water. The mounted sample was inverted and rotated on a polishing wheel while diamond paste was intermediately sprayed on the velvet cloth and the process was done continuously until a mirror-like surface was achieved. Then it was rinsed with water. The etching process was carried out where the etchant was prepared using 2% Nitric acid and 98% alcohol -2% Nital. The polished sample was held with a tongue and immersed in the etchant for a few seconds then rinsed with water and alcohol. The specimen was dried with a specimen dryer.

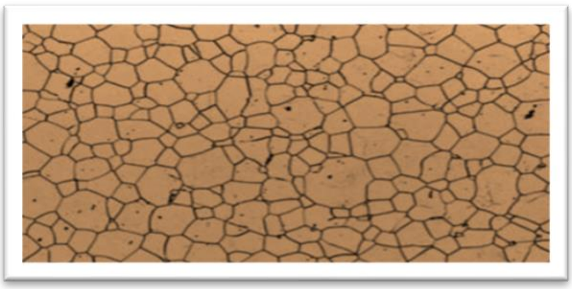

Plate 1a: Grit 1200 Coupon for Stainless Steel Coupon (SS 321 LOW ROUGH X500)

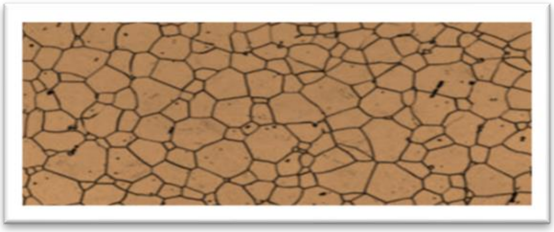

Plate 1b: Grit 400 Coupon for Stainless Steel Coupon (SS 321 MILD ROUGH X500)

Plate 1c: Grit 120 Coupon for Stainless Steel Coupon (SS 321 VERY ROUGH X500)

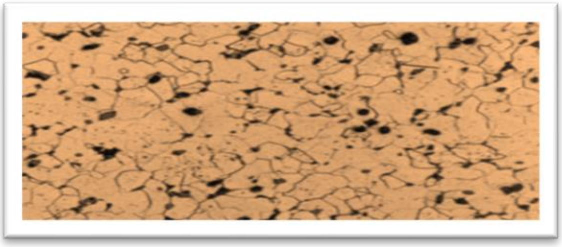

Plate 2a: Grit 1200 Coupon for Plain Carbon Steel Coupon (C 1020 LOW ROUGH X500)

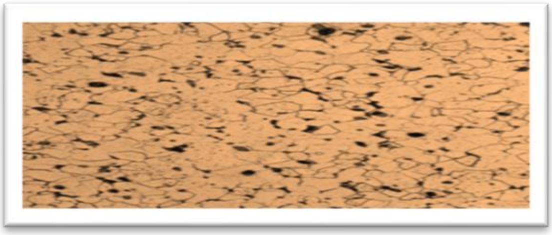

Plate 2b: Grit 400 Coupon for Plain Carbon Steel Coupon (C 1020 MILD ROUGH X500)

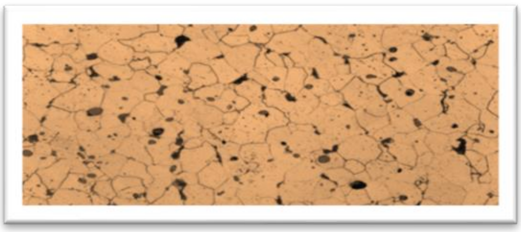

Plate 2c: Grit 120 Coupon for Plain Carbon Steel Coupon (C 1020 VERY ROUGH X500)

2.2.6. Linear Polarization Resistance Test

This technique is a reliable electrochemical procedure based on the principles outlined in ASTM G59 Standard practice for conducting potentio-dynamic polarization resistance measurement [16, 19]. There are two measurements made with this corrosion testing technique: Instantaneous corrosion rate

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measurements and Zero resistance Ammeter (Equivalent Pitting Rate)

2.2.6.1 Corrosion Testing

The three (3) different grades of coupon of grit numbers 120, 400 and 1200 for the stainless and Plain Carbon Steels were inserted into beakers containing IM HCl diluted into 250 ml of deionized water and the linear polarization test carried out at intervals of 5 minutes each for 40 minutes in total. Corrosion meter (MS1000) was used at those intervals and values/readings recorded in terms of high precision zero resistance ammeter (ZRA) and corrosion values [19].

2.2.6.2 Instantaneous Corrosion Rate Measurements

Instantaneous corrosion rate measurements are made with the linear polarization resistance (LPR) technique. The determination of a corrosion rate from the parameters measured with corrosion probes depend on faraday's law. The mass loss, current, potential, and changes in these variables are converted into a corrosion rate [17, 20].

Plate 3: Low carbon steel and Austenitic steel samples

Procedure for Linear Polarization Resistance Test

A sample of SS 304 Austenitic steel and C-1026 low carbon steel each was polished with grit paper of 220 roughnesses's to achieve the desired surface finish. Another sample of SS 304 steel and low carbon steel was polished with an adhesive paper of 320 roughnesses to obtain the result of the former. The same polishing process was undertaken on a different set of the metal samples using adhesive paper of 800 roughnesses.

The beaker was cleaned and 25ml of diluted hydrochloric acid was measured in it. One of the polished metal samples was immersed in the acid solution. After a period of five minutes in an eight (8) interval reading, the probe of the MS1000 instrument was put in contact with the metal sample immersed in the solution. The MS1000 instrument is used to read the corrosion rate and zero resistance amp (ZRA) value for each of the interval. The instrument is designed to calculate the corrosion rate of carbon steel and common grades of stainless steel. In other words, the programmed values of the Tafel slopes, equivalent weight and density are typical for carbon steel and common grades of stainless steel. When the interval session elapsed the immersed metal sample was retrieved. The acid solution that contained the metal sample was disposed of and a new set of 25ml hydrochloric acid was measured in the beaker. Respectively, each of the polished metal samples underwent the aforementioned process and the corrosion rate value and ZRA value was obtained for each of them. The values gotten from the experiment were recorded [21].

2.3. Economic Analysis

This experiment is capable of reducing losses and waste in the industry whereas being beneficial to industrialist and manufacturers. It would aid in appropriate material selection which in turn reduce cost in maintaining platforms in the oil and gas sector and other metal contained structures. This is possible because the experiment result would guide industrialists to predict the kind of property changes that will occur in a material from the metallography test due to variation in microstructure and on the preventive measures to be taken against corrosion [17].

III. RESULTS AND DISCUSSION

3.1 Results

The various results were displayed in tabular form for the different tests conducted. The corrosion tests of the grades of the plain carbon steel and stainless carbon steel, corrosion on the microstructures of the steels and the different hardness tests results carried out, analyzed and explained.

3.2.1 Corrosion Test Results for Low, Mid and Very Roughs for Plain Carbon and Stainless Steels

Figure 1 shows the relationship of corrosion rate of rough plain carbon steel with time. Before corrosion, the material values were small and after corrosion the corrosion rate were high. The corrosion rate fluctuates as a sinusoidal curve indicating the extent of corrosion. It is noticed that without corrosion, the values tends to be negative and after corrosion, the values becomes increases to indicate that more current generated as a result of corrosion. Compared to some of the literatures [7, 22], the result shown in Figure1is in agreement. There was corrosion for carbon steel metal was high due to high value of Fe in the elemental composition. Again, the graph indicates that corrosion rate is greater for very rough, > mild rough > low rough PCS. This is due to the fact that the value of Fe in these types of PCS are accordingly Fe for very rough > Fe for mild > Fe for low rough. This trend agrees with literatures.

Figure 2 depicts profiles of the different type of surfaces of which corrosion have chopped on plain carbon steel with time. The reading is obtained as a result of zero resistance ammeters (ZRA). This means that resistances affect the flow of current. It was expected that the more polish surface (rough PCS) should have very low values of ZRA than the roughest surface. From the experiment, this is what really happen and shows that the results obtained best explain the corrosion rate on the different surfaces varying with time. The low rough surface will have little or no corrosion taking place and so no impedance to the flow of current, hence high current readings compared to mild and rough surfaces of PCS. This result agrees with literatures [7, 22] as higher resistances were recorded for mild and very rough plain carbon steel surfaces, thus hinders the flow of current which inturn readings the values of ZRA as shown in Figure 2.

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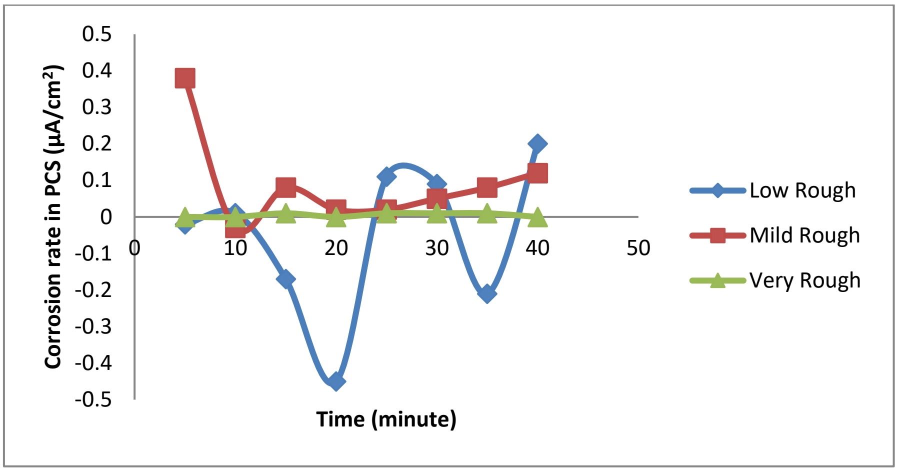

Fig. 1. Graph of Corrosion Rate attack on the Low Rough, Mild and very Rough Plain Carbon Steel (PCS) versus Time

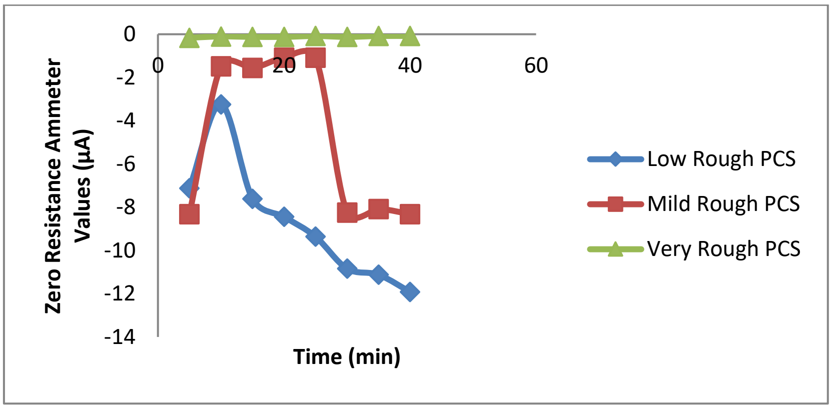

Fig. 2. Profile Variation of ZRA Values on the Grades of Plain Carbon Steel (PCS) versus Time

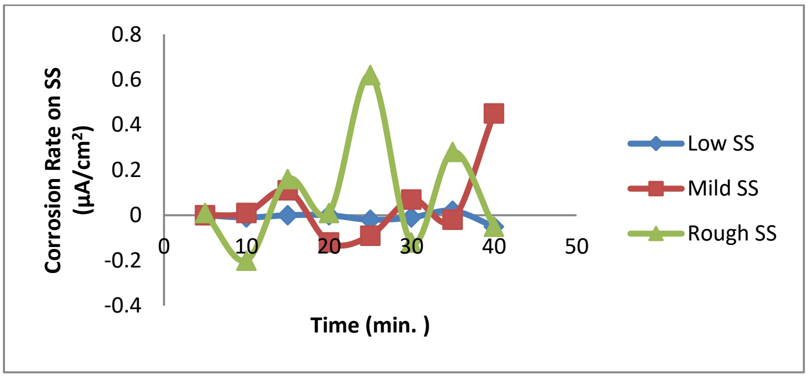

Fig. 3. Graph of Comparisons of the Corrosion Rate on the Types of Stainless Steel versus Time

Figure 3 demonstrates the relationship among the corrosion rates of the different surfaces of stainless steel (SS) with time. The profile in Figure 3 indicates that very rough surface is highly attacked by the effect of corrosion and gives high corrosion rate unlike other surfaces, mild and low rough stainless steels where there is variation of corrosion rates due of corrosion effect on the metal. Corrosion rates as indicated for stainless steel types is > very rough > mild rough > low rough surfaces. This result is comparable to literatures [15, 23] trend. It should also be noted that elemental composition of stainless steel show low Fe content to plain carbon steel, hence lower rate of corrosion for SS to PCS.

Figure 4 depicts the profile variation and comparison of the corrosion rate on the different surfaces of the stainless steel with time and measured using zero resistance ammeter instruments. Higher corrosion rate is seen for stainless steel whose surface is very rough, followed by mild stainless steel and then rough stainless steel. This actually tells us that corrosion is highest on rougher surfaces of metals than smooth ones. Similarly, ZRA values are lower for very rough surface of SS than mild and low surfaces due to higher resistance for such surface, little or no flow of current as shown in Figure 4. The result agrees with literatures [15, 23].

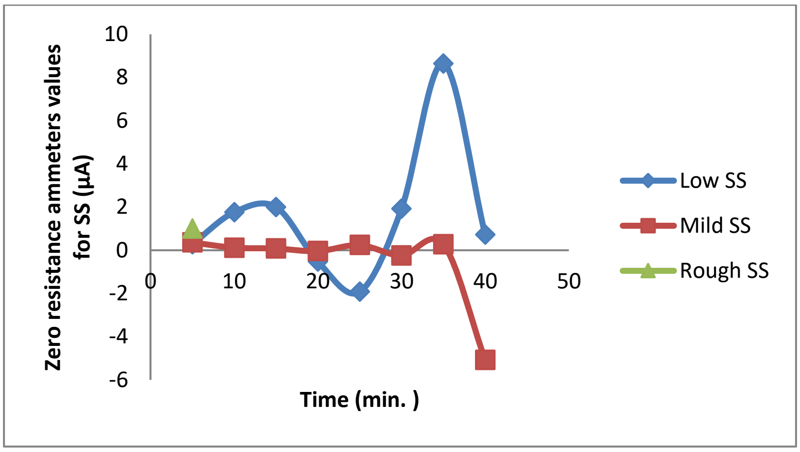

Fig. 4. Graph of Comparisons of the ZRA Types of Stainless Steel versus Time

3.2 The metallurgical microstructures after the LPR corrosion tests

Generally, the grains in these microstructures appear to be in strain packed condition, depicting weaker resistance to failures compared with the ones before the LPR test. The tables and figures below illustrate the compositions of the microstructures of the plain carbon and stainless steels compositions of the elements before and after corrosion. From the results carried out by TURRET ENGINEERING SERVICES LIMITED, there are very significant variations of the elemental compositions after corrosion on the microstructures for both steels. This shows that corrosion heavily attack steels and depends on the environmental conditions the equipment are exposed to.

TABLE 3. Elemental Composition (%) of the Microstructure of Plain Carbon Steel

Element	Composition (%) Before	Composition (%) After
Si	1.86	0.117
Ti	0.30	0.025
Cr	0.04	0.009
Mn	0.37	0.021
Fe	97.37	0.242
Zn	0.05	0.012

Table 3 demonstrates the elemental composition in percentage of the microstructure of plain carbon steel. Fe and Si are relatively predominant compared to Ti, Cr, Mn and Zn. From the elemental composition of the metal, one will concludes that Plain carbon steel is made up of Fe as it comprises of 0.9737 0f the 1.00. Fe ease corrosion as corrosion can only take place in the presence of Fe, moisture and air (oxygen). As shown, the composition of Fe is 0.9737 before corrosion and after corrosion, its composition is 0.242. The results show that the corrosion level is very high and the metal microstructure is finished. Within a very short period of time the material hardness will be less than 0.25 and breaks down because the lattice structure are dis-ordered and ruptured by the wearing of corrosion eaten on it. Even though Fe is predominant; other elements are being eaten by the corrosion as the result did not hide the fact.

Figure 5 depicts elemental composition of plain carbon steel with corrosion. The results show that Fe has been eaten by corrosion almost all comparable to other elements that form the metal. Zn and Cr gave us minimal corrosion attack than others elements. This was further explain on Table 3

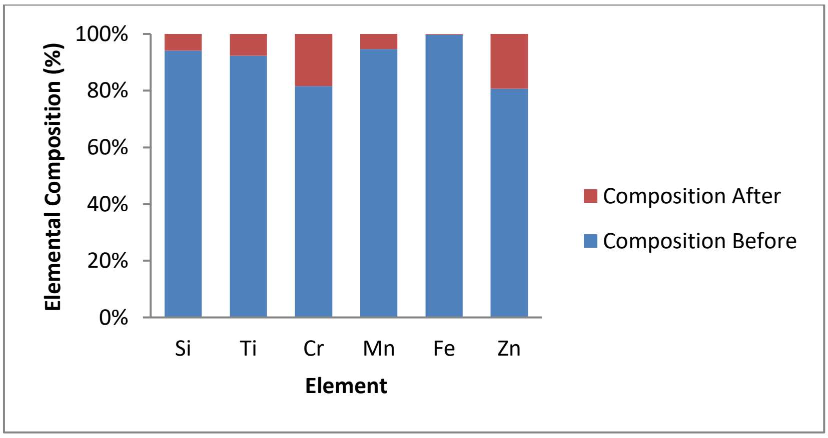

Fig. 5. Bar Chart showing Elemental Composition (Microstructure) of Plain Carbon Steel affected by Corrosion

TABLE 4. Elemental Composition (%) of the Microstructure of Stainless Steel

Element	Composition (%) Before	Composition (%) After
Si	1.44	0.105
Ti	0.08	0.022
Cr	17.41	0.116
Mn	1.90	0.094
Fe	69.27	0.246
Nb	0.01	0.004
Mo	0.39	0.01
Co	0.34	0.038
Cu	0.17	0.018

Table 4 depicts the composition in percentage of the microstructure of stainless steel after investigated by Turret Engineering Services Limited. It was found out that Fe too is dominant of stainless steel and aid corrosion in the present of air and moisture. The composition out of 1.00 is 0.6927 before corrosion and 0.246 after corrosion must have been taken place. Apart for Fe, Cr content is high of 0.1741 and 0.116 prior and post corrosion stages respectively. This stainless steel metal is also exposed to harsh environmental conditions.

Figure 6 show the corrosion on microstructure of stainless steel. Fe and Cr are highly affected by corrosion attack while Nb and Ti are less attack by corrosion. As explained in Table 4, the more the corrosion attacks on the metal, the weaker the metal to withstand tensile load.

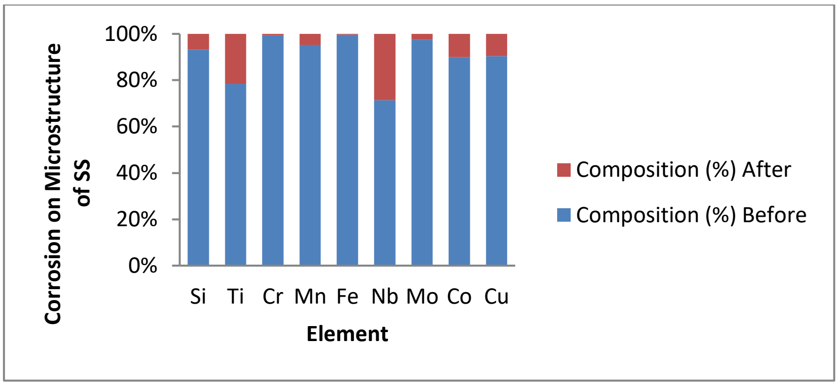

Fig. 6. Graph showing Corrosion on Microstructure of Stainless Steel

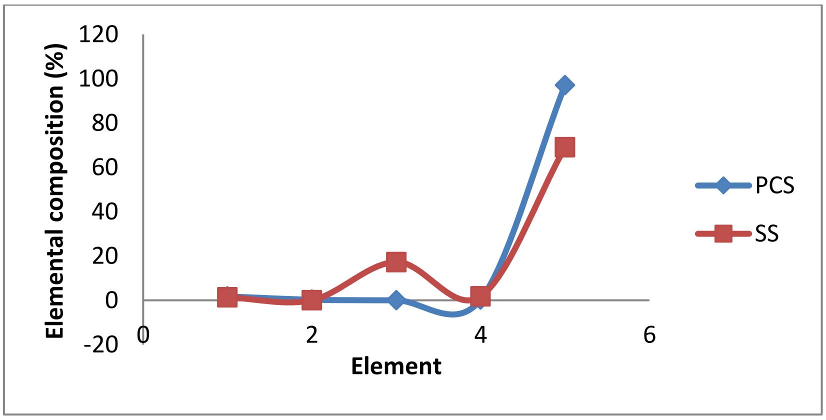

Fig. 7. Comparison graph of elemental composition of PCS and SS

Figure 7 depicts the similarity of the corrosion of Si, Ti, Cr, Mn, and Fe each assigned as 1, 2, 3, 4 and 5 respectively in the element-axis of Figure 7, in % for both the PCS and SS metals. It can be shown from the graph that the corrosion rate of plain carbon steel, (PCS), and stainless steel, (SS), varies in elemental composition due to the amount of Fe content present. Since Fe aid corrosion together with other factors, then, more of it present in such metal helps to degrade the metal fast as a result to exposure to corrosion agent. The graph indicates that PCS degrade more than SS because of more Fe content.

Figure 8 depicts the results conducted and displayed by the TURRET ENGINEERING SERVICES LIMITED for the microstructures of plain carbon steel and stainless steel. The compositions of the elements before and after corrosion were displayed as shown above. The results shows that there is significant changes in the corrosion values of both steels which means that corrosion has deeply affected the steels types. This result agrees with literatures trend [6, 15, and 19] as expected and indicates that the research article experimental results obtained from TURRET ENGINEERING SERVICES LIMITED was reliable and in good agreement.

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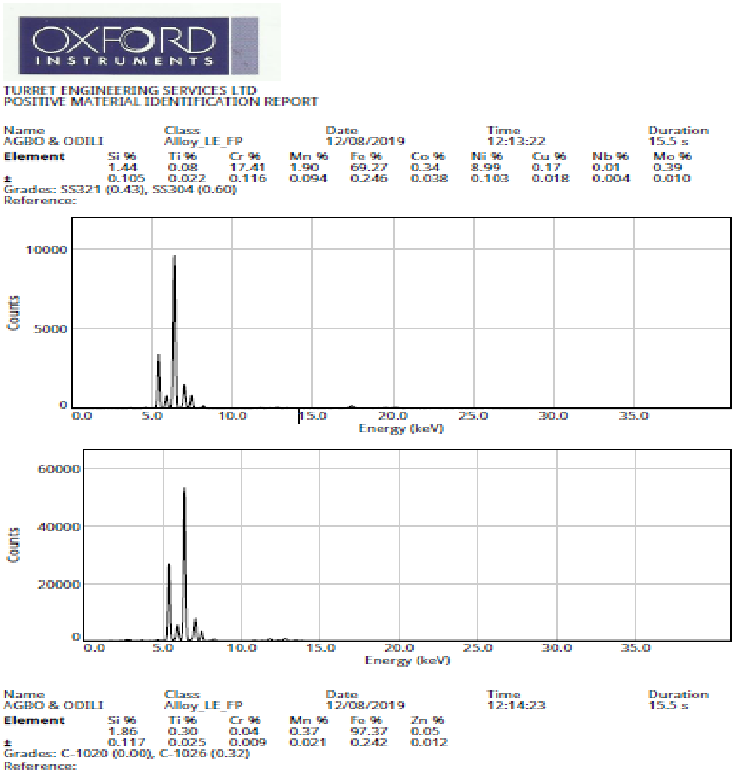

Fig. 8. Microstructures Results obtained from TURRET ENGINEERING SERVICE LIMITED for both Steels

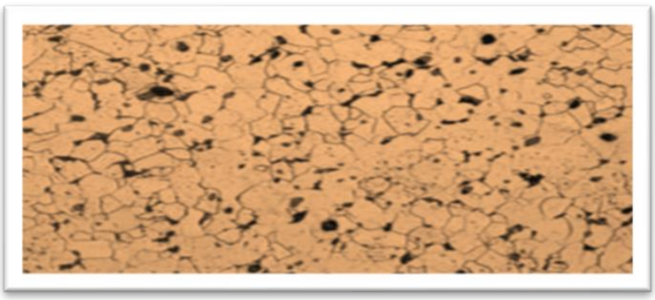

Fig. 9. Microstructures of Plain Carbon Steel affected due to Corrosion (C1020 Microstructure X 500)

Figure 9 demonstrates the corrosion levels on plain carbon steel of its microstructure when exposed in very harsh environmental conditions. As analyzed by the Turret Engineering Services Limited, the elements present in the metal are Si; Ti; Cr; Mn; Fe and Zn. The compositions in percentages is shown in Table 3 and depicts the corrosion rate on the metal is very rapid and high leading to plain carbon steel microstructure losing its hardness and reduction in life span. This further stated that the result of the experiment agrees with literatures values [6 and 7] which are a good indication of the reliability of the experimental data obtained.

Figure 10 shows the composition level of microstructure of the stainless steel before and after corrosion. The elements present in the metal comprises of Si, Ti, Cr, Fe, Mn, Co, Ni, Cu, Nb, and Mo after analysis by the Turret Engineering Services Limited. As indicated in Table 4 above, the composition levels in percentage before and after corrosion varies significantly due to the exposition of the stainless steel to harsh environmental conditions especially as sample was taken in the region of Niger Delta. Though the corrosion rate was not as high as that of PCS, due to less Fe content in SS than carbon steel, but there was corrosion that took place and the trend of the result was in agreement with research literatures [11 and 12].

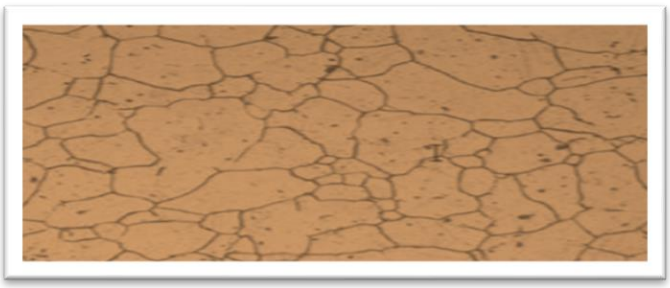

Fig. 10. Microstructures of Stainless Steel affected due to Corrosion (SS 321 Microstructure X 500)

3.3 Hardness test Results for Low, Mild and Very Roughs for Plain Carbon and Stainless Steels

The hardness result is summarized in Tables 5 and 6, and Figures 11 and12 for very rough, mild rough and low rough plain carbon and stainless steels.

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TABLE 5. Hardness test result after corrosion for stainless steel.

S/N	Very Rough (Grit 120) (HL)	Mild Rough (400) HL	Low Rough (Grit 1200) (HL)
1	270	276	300
2	297	300	296
3	342	350	355

Table 5 shows the hardness test result of corrosion analysis on the surface structures of the three phases i.e. the very, mid and low rough surfaces of the stainless steel. The result indicates that the more the roughness of the surface, the more the corrosion and vice versa. Thus smaller values for the corrosion test in Table 5, the more the corrosion eaten deeply on the surface of the metal. Low rough surface is like a well-polished surface and the less corrosion attacked the surface, the mild rough surface is neither too rough nor less rough, hence mild corrosion attacks takes place. The stainless steel metal generally have less corrosion attacks than plain carbon steel metal due to less Fe composition content in it as read by the Turret Engineering Services Limited. The values are 69.27% to 97.37%. Literatures [16 and 19] trends agrees with the result obtained, indicating reliability of the experimental data.

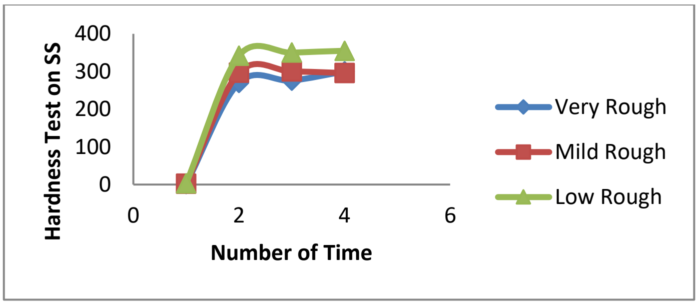

Fig. 11. Hardness Test Conducted on Stainless Steel on the three different grades versus Number of Times

Figure 11 depicts the hardness test on stainless steel on the different surfaces with number of time. Very rough surface has low values due to heavy corrosion attack on the surface than the other surfaces as discussed in Table 5.

TABLE 6. Hardness test result after corrosion for Plain Carbon steel.

S/N	Very Rough (Grit 120) (HL)	Mild Rough (400) HL	Low Rough (Grit 1200) (HL)
1	355	310	309
2	316	306	300
3	290	266	250

Similarly to Table 5, Table 6 describes the degree of corrosion on the metal surface of plain carbon steel (PCS). The hardness initially is very high and after the attacked on the carbon metal due to high Fe content, the more the attacked leading to reduced hardness of the metal compared to stainless steel metal after corrosion attack, even though the hardness initially was less. Generally, the very rough plain carbon steel surface experience heaviest attack by corrosion than the low rough surface due to the latter surface is polish and shining, hence inefficient for corrosion attack. The result confirms the theory of corrosion attack [18 and 19], meaning that the experimental analysis was good and agrees with the literatures values.

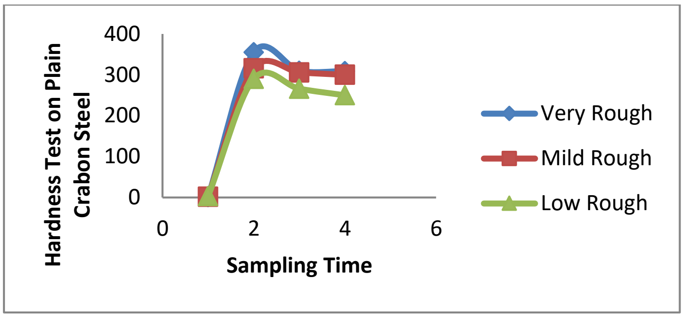

Fig. 12. Hardness Test Conducted on Plain Carbon Steel on the three different grades versus Sampling of Times

Similarly to Figure 11, Figure 12 shows different trend on the plain carbon steel. Very rough surfaces have higher values compared to other surfaces. This was also well explained in Table 6.

3.4. Comparison of plain carbon and stainless steels

From the experimental analysis, conducted by the Turret Engineering Services Limited, the following similarities and differences between the plain carbon steel and stainless steel were obtained. Plain Carbon and Stainless Steels have common features that both metals: comprises of Fe, Si, Ti, Cr, and Mn, and are deeply affected by corrosion either on the surface or microstructure, Fe content is high and predominantly made of Fe, and needed moisture and Air together with the Fe present for corrosion attack. All the investigation carried out jointly shows that corrosion is a common disease to pipes, metals and need to check regularly. However, these metals are different from one another in that: plain carbon steel is harder than stainless steel due to high content of Fe of 97.37% to 69.27%, stainless steel is made up of other elements such as Nb, Mo, Cu, and Ni, absent in plain carbon steel, plain carbon steel contains Zn, while stainless steel does not, corrosion rate is high in plain carbon steel than stainless steel due to the presence of high Fe content, after corrosion, stainless steel is still recommendable to plain carbon steel, whereas before corrosion, the reverse is the case, stainless steel is better material for transportation of fluids and constructions than plain carbon steel, and the lifespan of stainless steel is higher than plain carbon steel both the micro level or surface level.

IV. Conclusion

The experiment was conducted on six metal samples; three Austenitic Stainless Steel (SS304) and Low Carbon Steel (C-1020) each. It involved accelerated corrosion and metallography tests. These were done after the metal surfaces were polished with three grades of emery paper – 220, 320 and 800 grits. The distance between the rough surfaces was done with a surface roughness tester which measured 0.271, 0.935 and 1.024 microns respectively. The accelerated corrosion test revealed that low carbon steel with surface roughness of 0.935 microns has the instantaneous corrosion rate although at the initial stage. Also, low carbon steel with the surface roughness of 0.935 microns corrodes faster than the other samples.

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Austenitic stainless steel with surface roughness of 0.271 has the lowest rate of corrosion. Thus from the experiment it is deduced that for both low carbon steel and stainless steel, the rate of corrosion is directly proportional to the surface roughness. However, for surface roughness of 1.024 in low carbon steel and austenitic steel the instantaneous corrosion rate is almost negligible. Generally, the grains in microstructures of corroded metals appear to be in strain packed condition, depicting weaker resistance to failures compared with the ones before the linear polarization test.

V. Recommendation

Stainless steel metals should be recommended for fluid transportation and industrial activities than plain carbon steel due to less corrosion attack as a result of low Fe content. Only environment where exposure of moisture is not present then can we use low carbon steel for construction purposes. In future works and further experimentation, the depth of pitting in the accelerated corrosion testing can be evaluated. Also it can be investigated why the corrosion rate for austenitic steel and low carbon steel tended to zero for surface roughness of 1.024.

References

[1] Cramer, S.D & Covino, B.S., (2008). Corrosion: fundamentals, testing and protection, ASM International Handbook, vol. 134

[2] Roberge, P., (2008). *Corrosion Engineering Principles and Practice*, McGraw Hill: New York

[3] Marcus, P & Oudew, J, (1995). *Corrosion Mechanizes in Theory and Practice*, Marcel Dekker, New York: USA

[4] Ikechukwu, A.S., Obioma, E., & Ugochukwu, N.H. (2014). Studies on corrosion characterization of carbon steel exposed to Na_2CO_3, Na_2SO_4 and NaCl solution of different concentrations. *International Journal of Engineering Science*, 3:48-60

[5] Toloei, A.S., Stoilov, V., & Northwood, D.O. (2013). The effect of different surface topographic on the corrosion behaviour of Ni:WIT transaction on engineering sciences. *Materials Characterization*, 77(6):194

[6] Breton, S.B., Vignal, V., Herbet, F & Coudert, J.B. (2016). Infleunce of machining on the microstructure, mechanical properties and corrosion behaviour of a low carbon and martensitic stainless steel. *Procedia CIRP*, 46: 331-335

[7] Handoko, W., Pahlevani, F. & Sahajwalla, V. (2017). Corrosion behaviour of dual-phase high carbon steel-microstructure influence. *Journal of Manufacturing and Materials Processing,* 1 (21): 1-9

[8] Deepak, D., Katerina, L & Thomas B, (2017). Carbon Steel Corrosion: A review of Key surface Properties and Characterization Methods. *RSC Adv.,* 7: 4550-4610

[9] Suber, T., Muller, Y., Schmutz, P. & Vantrzebi, O. (2005). Micro electrochemical studies of pit initiation on high purity and ultra-high purity Al: *Advanced Engineering Materials*, 9 (5) 339-348

[10] Makarenko, N., Kharchenko, U., Zernukhova, L. (2011). Effect of amino acids on corrosion of copper and steel in acid medium. *Russ. J. Chem*, 84: 1362-1365

[11] Arafin, M.A & Szpunar, J.A, (2009). Carbon steel corrosion. *Corrosion Science*, 51: 119-128

[12] Lu, S.V., Chen, Y.B., Yao, K.F., Wang, M.H., & Ge, X-V (2014). Influence of heat treatment on microstructure evolution surface roughness and corrosion resistance of a martensitic stainless steel. *Journal of Applied Electrochemistry,* 80: 875-883

[13] Jason, R.T., Gary, P.H., Olivia, K.D & Guha, M. (2016). Microstructure and Corrosion Resistance of Laser additively manufactured 316L stainless steel. *The minerals, metals and materials society*, 5:234-245

[14] Mirjam, B.L., Crt, M., Tadeja, K., Bostjan, M & Janez, K., (2014). The effect of surface roughness on the corrosion properties of type AISI 304 stianless steel in dil. NaCl and Urban Rain solution. *Journal of Materials Engineering and Performance,* 3(1): 3-13

[15] Mohammed, H. M & Almed, F.S., (2017). Effect of Heat Treatment and surface finish on the Crevice Corrosion Resistance of Martensitic stainless steel, *Basrah Journal of Engineering Sciences*, vol. 17, no. 2: 9-21

[16] American Society for Testing and Materials (ASTM) G5-94, (2004). Standard reference test method for making Potentiostatic and Potentiodynamic Polarization measurements: *Annual Book of ASTM Standards*, vol. 03.02. Philadelphia, PA: USA

[17] Callister, W.D & Rethwisch, D.G (2007). Material Science and Engineering: An Introduction. Wiley New York: USA

[18] Moulder, J.F., Stickles, W.F., Sobol, P.E. & Bomben, K.D. (2008). X-ray photoelectron Spectroscopy, and Physical Electronics, Eden Prairie, MN

[19] National Association of Corrosion Engineers (NACE) Standard TM0169-2000, (2000). Standard Test Method: Laboratory Corrosion of Testing metals. *NACE International*, Houston, Texas: USA

[20] Abechi, S.E., Nwokem, N.C., Shallagwe, G.A., Nwokem, C.O & Wyasu, G, (2020). Linear Polarization studies of the corrosion inhibition of Al using Leaves extract of *Alcalypha wilkesians. Science World Journal,* 15(3):116-118

[21] Aly, O.F & Neto, M.M, (2014).Stress corrosion cracking. Chapter 4: Development in corrosion protection, 65-79

[22] Asma, R.N., Yuli, P & Moktar, C. (2011). Study the effect of surface finish on corrosion of carbon steel in CO_2 environment. *Journal of Applied Sciences*, 11 (11): 2053-2057

[23] Cochorane, D & Henzel, M., (2005). Guide to stainless steel finishes, building series, vol. 1 Euro Inox, 2005

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