Microstructural Evaluations of Mild Steel and HT250 Grey Cast Iron in Ethanol Environment

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ABSTRACT: The study focused on the response of mild steel and HT250 grey cast iron in varying ethanol concentration. First, a robust review of both materials' behaviour under different environment was established using microstructural evolutions. Secondly, 30 × 30 × 10 mm dimension of both materials were employed in the study by immersing them in varying ethanol concentrations of BG-43 %, ESG- 42 %, CG-43 %, SQD- 42 % using distilled water as control. The microstructural behaviour showed that every of the sample responded according to the medium of interaction (ethanol). The degree of surface damage also depends on the ethanol concentration and the heavy presence of Fe and oxygen especially in that of grey cast iron. Corrosion cracks and deposits can be attributed to the reaction between the surface and the ethanol. Thus, environment of application is important in material selection. Results suggests that the microstructural changes provide to the material scientist the qualitative corrosion information of these materials in different environment. Conclusively, the study has enlightened the design engineers and material specialist on the need for proper material selection during engineering design.

KEYWORDS: Microstructure, mild steel, grey cast iron, ethanol, distilled water, corrosion

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I. INTRODUCTION

Engineering materials are vast in nature with different properties (Abavisani *et al*., 2021). The variation in their respective properties calls for their various engineering applications (Faried *et al*., 2021). It is important to understand their behaviour to enable the engineer select the best material for the right application (Xiong *et al*., 2021). More so, it has become pertinent to not only understand how this material behave in real life, but also know the cause of the behaviour (Oviedo-Amezquita *et al*., 2021). Basically, the behaviour and the production of engineering materials entails the critical study and understanding of the structure of the material, material behaviour in varying environment, physical and chemical properties and material property modification (Yang *et al*., 2021). According to Wang *et al*. (2021) structural analysis of an engineering material requires an in-depth understanding of different bonds that the material is made of such as; electrovalent, covalent hydrogen bonding, crystalline nature and amorphous nature of the material. A study has shown that for a component to perform to its optimum efficiency in real life, several mechanical properties such as fatigue, creep, fracture, ductility strength, tension and toughness must be critically analyzed (Wang *et al*., 2021). The result of these analyses usually informs the material engineers on the need to modify the materials via various heat treatments (Liu *et al*., 2021). Mechanical properties obtained from the various tests will inform the designer on the best structural design method (Zheng *et al*., 2021). It was established that various shapes and sizes can be obtained in the industry via application of forces (Rathore & Saxena, 2021). For example, rolling of flat metal sheet to form a cylindrical shape requires an external force application (Pawar, Park, Hu & Wang, 2020). It is therefore important to a designer to understand the response of this material to the applied force (Tung *et al*., 2021). The behaviour of a component under dynamic force is an important consideration (Nazarenko *et al*., 2021). According to Gandhi and (Asif *et al*., 2021), gear teeth are subjected to dynamic forces and if the forces are in excess, vibration occurs which will cause fatigue and eventual crack on the teeth (Zhu *et al*., 2021). Mild steel has been used in different industries owing to their ease of fabrication, strength and low cost (Boulhaoua *et al*., 2021). It is referred to as low carbon steel with a range of carbon of between 0.05-0.25 percent (Gandhi *et al*., 2020). It is a combination of iron and ferrite (Wang et al., 2020). Mild steel can be used in machinery parts, steel frame structures, gates and building reinforcement (Rajitha & Mohana, 2020). However, mild steel suffer degradation in an aggressive environment and currently and there is an urgent demand to investigate the behaviour of mild steel in different environment (Suraj, 2021). For instance, running a gearbox made from mild steel at high-speed subject the teeth to increased number of contact and allow repeated stress to set in (Bergstedt *et al*., 2021). This in turn will cause damage to the gear teeth because of micropitting, thereby

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causing the eventual failure of the gear material (Matkovič & Kalin, 2021). A study has established that mild steel is a better material compared to other materials in a specific industry like the structural constructions and the refineries (Bastos *et al*., 2020). Karthick & Yoganandam, (2021) reported that, the possibility of making a reliable component from mild steel lies in the fundamental understanding of their behaviour in different environment. More so, their degradation behaviour in a corrosive environment becomes a major limitation of mild steel (Devikala *et al*., 2019). The petrochemical industries majorly suffer problems since the major pipeline materials are made from mild steel and the environment contains some corrosive substance (Loto, 2017). Despite the efforts of many researches to combat this problem, mild steel corrosion is still a major problem to many industries. There is a need for urgent study on the way to avert this mayhem (Fawzy *et al*., 2021). On the contrary, to mild steel application, grey cast iron finds application in the industry because of its high stiffness, damping properties, high thermal conductivity and high heat capacity (Saluja & Singh, 2020). It has been deployed in the fabrication of major components of the internal combustion engine such as the engineer cylinder block, piston, flywheel and braking system (Weng *et al*.,2020). In comparison with mild steel, it has a weight percentage of carbon ranging from 2 - 4% (ELSawy *et al*., 2017). The manufacturability and the ability to modify cast iron using the alloying elements gives it wide deployment in different engineering applications (Razaq *et al*., 2019). Apart from ease of machining and its ability to dampen vibration, cast iron also, have a high compressibility property, increased wear resistance and high corrosion resistance (Uzun, 2019). Grey cast iron has a dark grey fracture in nature due to its graphitic microstructure. This suggest the use of grey cast iron in machine tool fabrication (Akinribide *et al*., 2019). According to Cortés & Castillo, (2007), comparison of grey cast iron to polymer concrete in terms of their dynamic properties showed that grey cast iron performed better and withstand abrasion under high speed. In addition, an assessment of its wear behaviour showed a better wear resistance in automobile applications. Grey cast iron had been tested in different corrosive environment to ascertain its sustainability in real life application. For instance, Vázquez *et al*. (2021) reported that grey cast iron survived in both paraloid B-72 and organic compound. This equally implies that both solutions have a synergistic effect on the material. Despite the application of grey cast iron in different industries owing to its properties, it can easily deform under strain (Ferreira, 2002). More so, corrosion is a major problem, which tend to reduce its mechanical properties (Beniwal & Saxena, 2020). Furthermore, lack of heat treatment of the material could cause deformation and the eventual loss of the material (Singhal & Saxena, 2020). Going by the variations in the properties and applications of mild steel and grey cast iron, it is obvious that there is a need for a general comparison of their behaviour in varying environment. This will inform a material engineer and design engineer on the selection of the right material for any application. Failure of engineering material would be limited. The rate of chemical degradation of engineering materials is becoming alarming especially in the industry. This mechanical failure has caused several reductions in the functionalities of engineering components. Mild steel has been recognized as one of the materials with promising mechanical strength, however, a study has established that, mild steel is prone to chemical attack in acidic environment. It is impossible to make use of this material without inhibitors. Bioethanol is recognized as one of the promising fuels for automobile engine application. A study has shown that the corrosion behaviour of the bioethanol in the automobile components is increasing (Salawu *et al*., 2020). The recognition of bioethanol as a future first generation fuel poses and issue. Jiang *et al*. (2020) established that pitting corrosion of mild steel pipelines poses a serious structural integrity problem in Shale water plants and this is attributed to the activities of the microorganisms and the presence of chloride in the water. Also, according to Chafiq *et al*. (2021) scientists have improved in the area of the use of inhibitors. For instance, adoption of hydrazine as an inhibitor for mild steel in hydrochloric acid (HCL) showed a better performance in that environment. More so, the synergistic adoption of sodium lignosulfonate-zinc acetate (SLZA) system and its consequent impact on the corrosion prevention of mild steel in the 3.5 wt% NaCl was found to be excellent (Ahangar *et al*., 2020). AELE was reported to have excellent antifouling property when used for mild steel protection, hence the need to investigate its potential as an inhibitor (Krishnan *et al*., 2018). Hemapriya *et al*. (2020) reported that biodegradable wastes have significantly found application in the area of corrosion inhibition. It was established that human hair extract in Hydrochloric acid mitigated the corrosion activities of mild steel in such environment. The weight loss and the electrochemical analyses showed that there was adsorption on the surface of the metal when the Langmuir isotherm was investigated. The behaviour of rhodmine blue and that of cationic surfactant on mild steel corrosion in hydrochloric acid was equally reported to have combined effects as the inhibition efficiency was high (Aslam *et al*., 2021). Also, a study established that the presence of meat extract in hydrochloric acid, will impede the initial crack initiation on mild steel surface as well as propagation. Pitting corrosion would be hindered from occurring at the metal surface (Eftekhari *et al*., 2021). Joseph *et al*. (2021) reported that it was possible to predict the behaviour of mild steel in the presence of fluid extracts developed from agro waste. This was achieved by the immersion of the prepared coupons of mild steel in the extracts of a mixture of coconut and egg shell fluid at different time. The result showed that it is possible to monitor the thermodynamic behaviour of the mild steel material while in application, especially for those used in hammer mill fabrication because of their interaction with different oil used in the grinding process. The combined effect of extracts from walnut green husk and potassium iodide on a mild steel material in the presence of solution containing trichloroacetic acid showed a good inhibition efficiency (Li & Deng, 2020). According to Gnanasekaran *et al*. (2020) the inhibition efficiency of extracts from cowries on mild steel in the presence of tamarin seed was equally established to be high. Mild steel is however, recognized to behave better in the presence of inhibitors. Despite the aforementioned properties and the corrosion behaviour of mild steel in varying environment, many studies and particularly industries where mild steel materials are usually deployed suffers severe degradation in their components parts of the machines. Many researchers suggested that mild steel could last for years if the thickness is increased, but it is worth noting that, no matter the increase in thickness of a material, the most important thing is the binding force between the molecules of the material. It has become a major issue to researchers. Grey cast iron is found to have less tensile strength and corrosion resistance; however, they are known to have great compressive strength compared to low and medium steel. Grey cast iron has graphite flakes which controlled the mechanical behaviour of the material. Because of their weight, they are usually deployed into the fabrications of housings because of its stiffness as well as in the fabrication of internal combustion engine parts (Ravikumar *et al*., 2021). Grey cast iron is characterised by certain mechanical properties that suggests its numerous applications in the industry. It has a tensile strength which ranges from 100-350 MPa. It is possible to engage it in the fabrication of several engineering parts due to its strength. More so, its ability to withstand compressive strength suggest its applications in fabricating pressure parts in heavy machineries. Grey cast iron has the ability to resist wear. This is the reason for its general applications in machinery parts. According to Wang *et al*. (2020) grey cast iron has variable modulus of elasticity which is as result of the presence of graphite flakes. This makes it possible for grey cast iron to behave plastic under slight application of stress. The modulus of elasticity of grey cast iron varies with the grade of the material. Although, it is a brittle material and does not behave stable under impact load. In terms of process performance, grey cast iron has excellent fluidity and this why it can be turned into thin-walled and complex components. Its shrinkage ability is mitigated by the graphitization during expansion process, this can greatly help in reducing shrinkage and residual stress during solidification. thermal stress and stress in casting contribute to the cracking of grey cast iron during casting process. However, the variation in the casting structure will lead to the differences we have in strength and hardness of the casting (Zhao *et al*., 2019; Wang *et al*., 2020). Basically, the presence of graphite flakes in grey cast iron improves the metal matrix and this equally helps in improving the machinability of the material. Cementite presence reduces the machinability of grey cast iron (Giacomelli *et al*., 2018). This is the reason why grey cast iron heat treatment is considered as a careful process (Song *et al*., 2018). Grey cast iron is known to have the ability to dampen vibration and this is what informed the material engineers in the choice of its usage in the fabrication of gears and internal combustion engine components (Wang *et al*., 2020). It has excellent wear resistance in sliding and rolling condition, heat and fatigue resistance property and very compact in nature (Sadeghi *et al*., 2017). Furthermore, the addition of copper and molybdenum to grey cast iron causes the pearlite formation and it increases the tensile strength as well as the hardness (Masuda *et al*., 2017). There could be a reduction in the impact energy. Thus, copper and molybdenum additions help in reducing the graphite flakes and improving the pearlite content as well as microstructure of the grey cast iron. Modification of grey cast iron for engineering applications has become a great interest to researchers. For instance, addition of niobium elements to grey cast iron increases hardness which will eventually reduce the wear rate as well as reducing the lamellar spacing in the graphite layer (Riemschneider *et al*., 2021). The addition of niobium led to the modifications and improvement of the microstructure of grey cast iron.

Conclusively, the literature search showed that both mild steel and grey cast iron suffers severe degradation in both acidic and ethanol environment. Despite, the available inhibitors, both materials still suffer high rate of degradation. The need to know a comparison between the two to establish which is better in an ethanol environment as well as recommend which of them is better for producing machinery parts or components.

II. METHODOLOGY

A. *Mild Steel*

Mild steel otherwise known as low carbon steel was selected for this study because of its high tensile strength and high impact strength which are in important machine design. It has a carbon content ranging between 0.04 – 0.30 percent. It is recognized as one of the largest groups of steel because of its formability into various shape, from flat to structural steel and can be modified by adding other elements. Mild steel was obtained from the Nigerian market for this study.

B. *Grey Iron*

Grey cast iron has a graphitic microstructure and has a chemical composition ranging from 2.5 – 4.0 % of carbon and 1 – 3 % of silicon content. The high compressive, tensile and resistance to deformation is what suggests its use for the experimental purpose. It has wide applications in engineering. The class of HT250 grey cast iron was employed for the study because of its suitability in gear production.

C. *Blended brands of ethanol beverage and distilled water*

Blending can be defined as a technique for alcohol or wine production. The study employed different blends and varying concentrations of the ethanol beverage. The reason behind the use of these solutions is as a result of the presence of some elements which cause corrosion of machine components such as gears, shaft, sprockets and housings. Also, both materials that is mild steel and grey cast iron are prominent materials used for gear components in bottling machine which made them susceptible to corrosion damage. Distilled water was equally used as part of the solution because of its purity and absence of trace elements. This is to be able to understand the behaviour of the material in such media before it can be suggested for material specialists during design. Safe engineering design would be encouraged. Table 1 show the various brand of ethanol using distilled water as a control. The weight loss was done by immersing each sample in various brands of blended ethanol for about twenty (28) days after which the microstructures were examined.

D. *Emery Cloth*

Different sizes of emery clothe was used in grinding and polishing the metal surfaces to remove rust and edges as well as scratched surface from the metal before the commencement of the experiment. This provided a smooth surface finish and a better result during characterization.

Table 1: Show the various brand of ethanol using distilled water as a control

Ethanol Solution	% v/v concentration
Sample A (BG)	43
Sample B (ESG)	42
Sample C (CG)	43
Sample D (SQD)	42
Control Solution (Sample E)	Distilled water

E. *Nitric acid*

0-0.5 % nitric acid was used for the etching process of the metal to be able to remove the thin layers introduced during grinding or polishing process. It helps to study the variation in the topography and the reflectivity in the microstructure of both the mild steel and the grey cast iron metals.

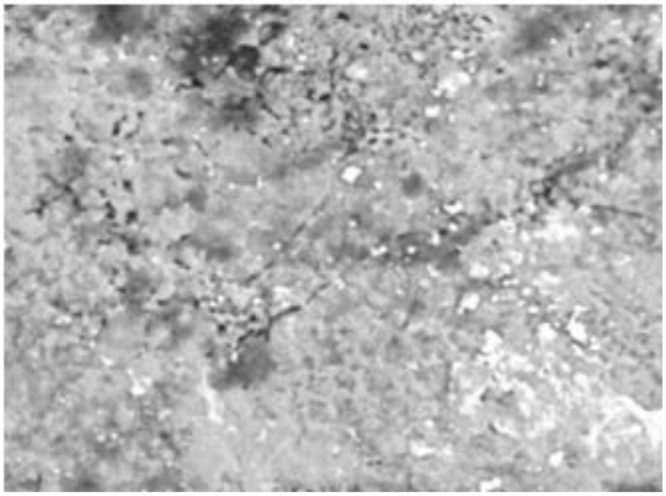


Fig a: SEM Morphology of As-received mild steel

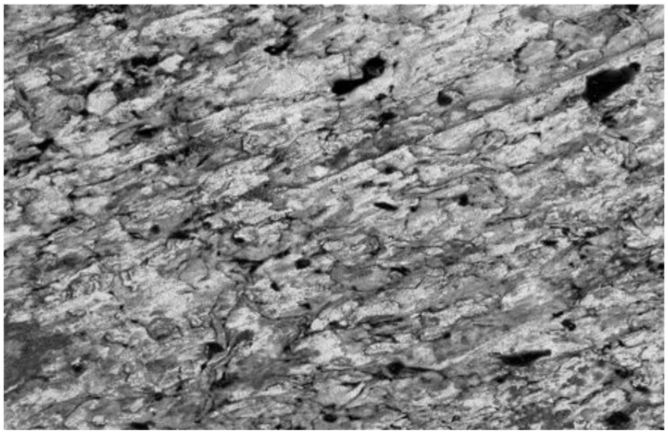


Fig b: SEM Morphology of as-received grey cast iron

III. RESULTS AND DISCUSSION

Figure 1 represents the SEM/EDS microstructure of sample immersed in 43% concentration of the ethanol solution. From the microstructure, it was observed that there were shiny corrosion deposits (oxide) at the mild steel surface. As a result, it is demonstrable that the mild steel undergoes a severe corrosion attack. This could be due to the percentage concentration of the ethanol solution and owing to the facts that it was immersed for considerable number of days, thus having an integrated corrosion severity. Therefore, material failure will be inevitable while in application. Similarly, the EDS result equally displayed the presence of certain elements in their varying weight by percentage. This include Fe (95%), Fluorine (2.5%), oxygen (2.0%) and aluminium (0.2%). The chemical activeness in iron and the percentage displayed showed that it contributed immensely to the corrosion of the metal surface especially in the presence of the other elements.

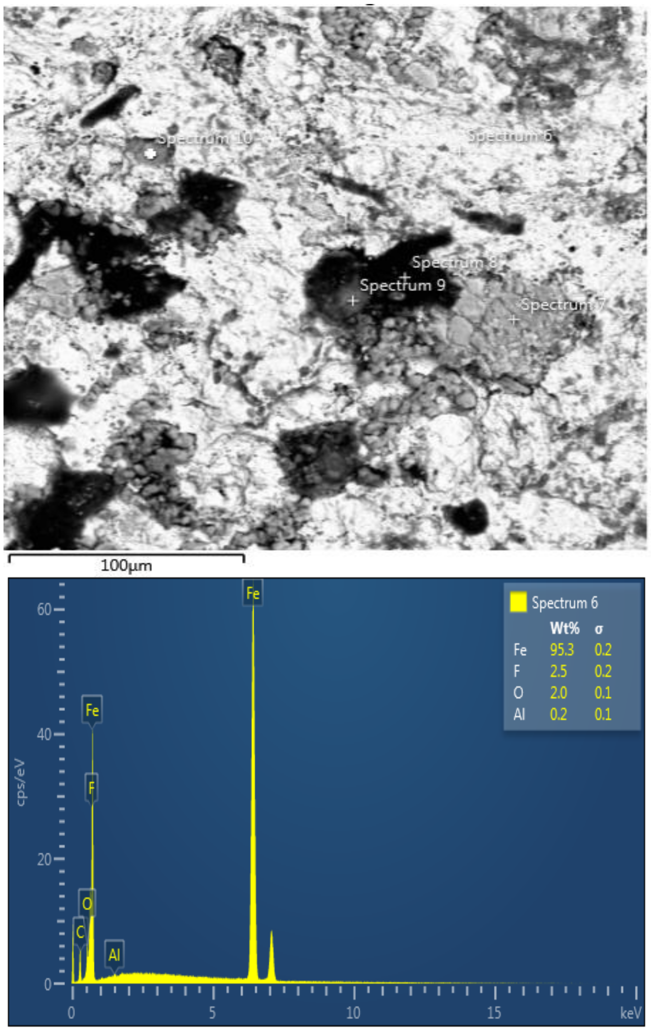


Figure 1: SEM/EDS of mild steel sample immersed in solution A

Furthermore, Figure 2 shows the microstructure of sample immersed in 42 % ethanol concentration. The specimen was observed to have undergone intergranular corrosion. The microstructure demonstrates that the crystallites boundaries of the specimen were more affected than the inside. Although, dark corrosion deposits were equally observed. The predominant deposits of elements as observed from the EDS microstructure include Fe, O, Si and Cl. While the less dominant element is F, Na, Mn, Cu, K, Al, Cr and Ca. Out of all the element, it could be depicted that Fe having a greater percentage by weight could have come from the mild steel which is the base metal.

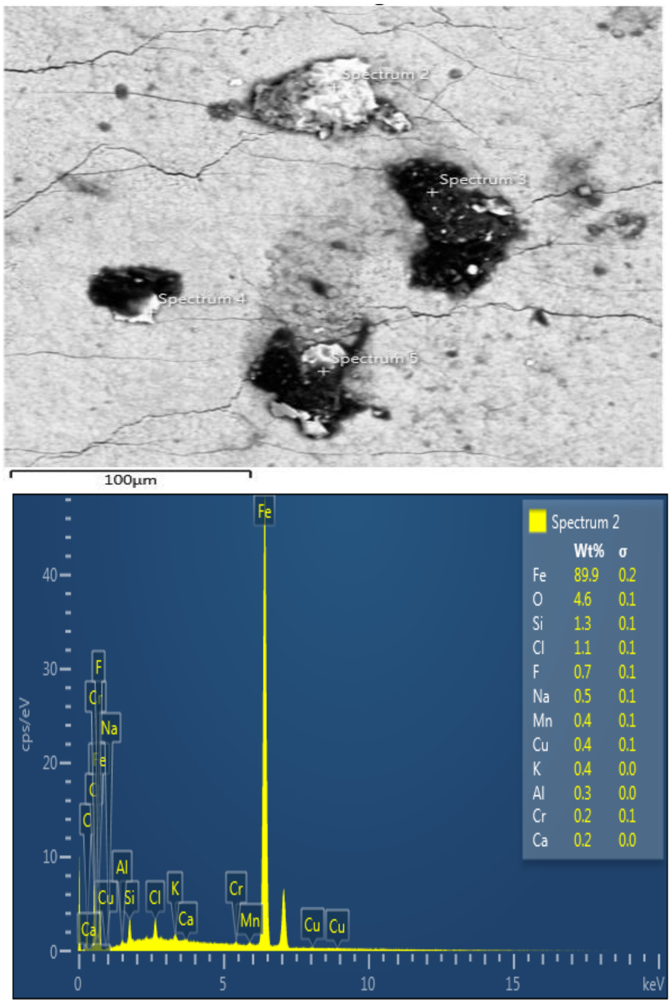
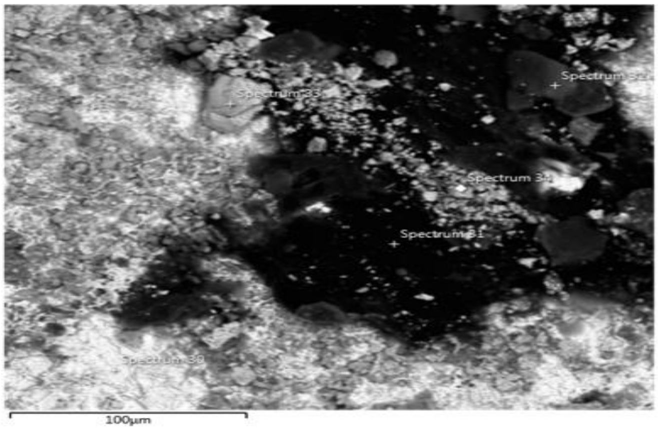


Figure 2: SEM/EDS of mild steel sample immersed in solution B

Figure 3 also represent the microstructure of sample immersed in 43 % ethanol solution which is a different brand from sample A. Dark and white corrosion deposits dominate the entire surface in an admixture pattern. It is noteworthy that there was presence of ferric oxide as a result of the solubility of oxygen in the ethanol-containing solution. Since, ethanol is a weak acid, possible attack took place which resulted in the admixed corrosion observed on the metal surface. The EDS analysis showed that Fe, O and F were present.



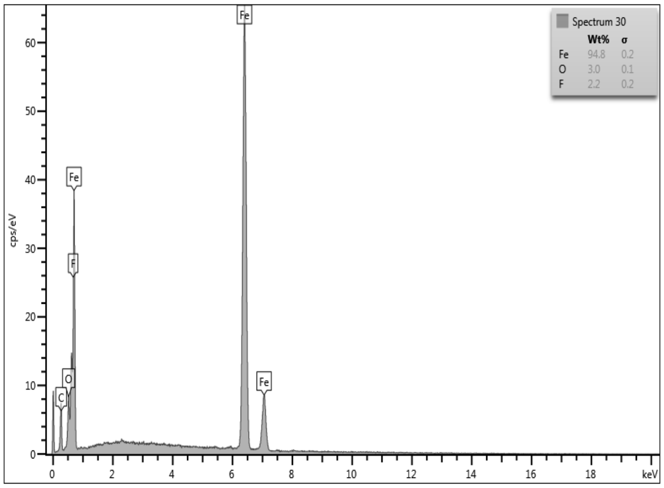


Figure 3: SEM/EDS of mild steel sample immersed in solution C

Additionally, Figure 4 shows the SEM/EDS microstructure of sample D immersed in 42 % ethanol concentration. Corrosion deposits as well as corrosion cracks were observed. The severity of the corrosion cracks could be traced to the concentration as well as the fact that the ethanol solution is coloured (root extract) compared to the spirit brand of the ethanol solution. Fe and O are the dominant elements as observed from the EDS.

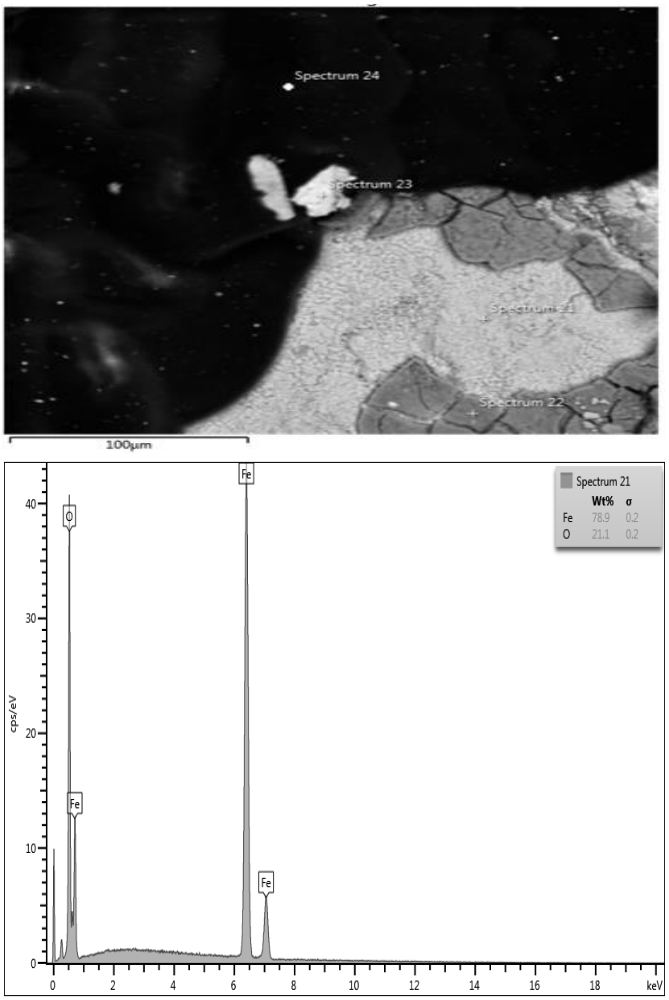


Figure 4: SEM/EDS of mild steel sample immersed in solution D

Figure 5 shows the SEM/EDS microstructure of sample E immersed in distilled water. White corrosion deposits and cracks were observed at the surface. Although, not as severe as what was observed from the samples immersed in the ethanol solutions. Thus, it is noteworthy to say that water contain fast ions which aid corrosion compared to the ethanol which is a weak acid. More so, the integral effects of chloride presence and oxygen content will lead to the erosion of the specimen surface and the eventual loss in mass. The proportionality of the corrosion rate of the material in distilled water with that of the ethanol can also be attributed to the diffusion of the oxygen dissolved. Hence, mild steel material properties must be improved in other to thrive in such environment of application.

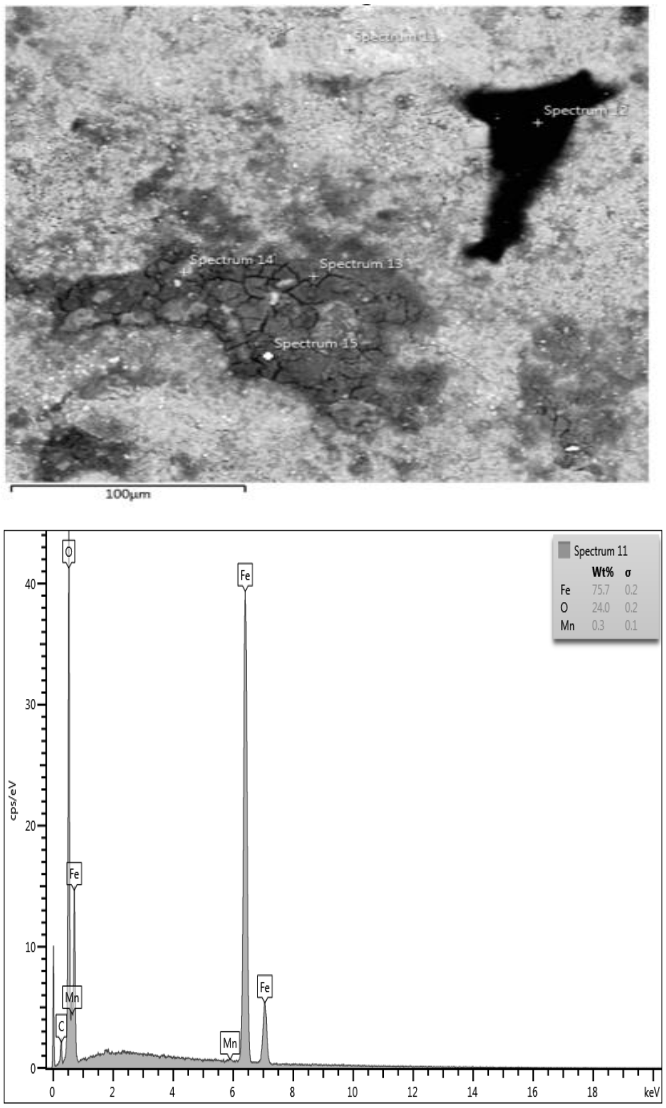


Fig 5: SEM/EDS of mild steel sample immersed in solution E (Distilled water) Control

Figure 6 show the HT250 grey cast iron immersed in the same concentration of ethanol solution as in the case of mild steel Figure 1. It could be observed from the microstructure that the entire surface of the material is dominated with white corrosion deposits and some dark spherical curves representing corrosion cracks. It was also noticed that the cracks are at a nucleation stage which could result into intergranular cracks if not checked appropriately.

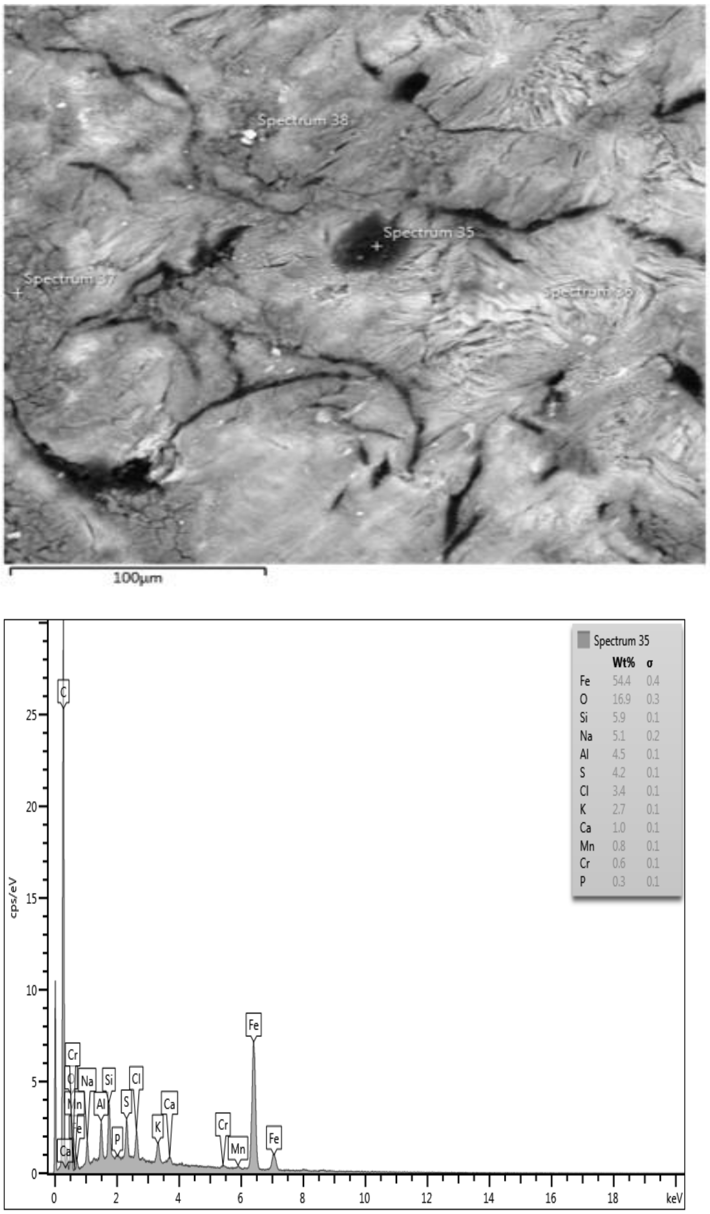


Figure 6: SEM/EDS of HT250 grey cast iron sample immersed in solution A

However, Figure 7 showed a severe corrosion damage in virtually the entire surface of the material. This observation could be attributed to the heavy presence of the parent metal Fe and oxygen as analysed from the EDS microstructure.

Furthermore, Figure 8 show the microstructure of sample C in 43 % ethanol concentration. The specimen equally suffered corrosion attack as observed form the major and minor corrosion cracks on the entire region. More so, dark and white corrosion spots were formed on the surface of the material. The implication of these corrosion deposit is that they form a solid layer which primarily cause the dissolution of the material.

Figure 9 represent the SEM/EDS of the sample D immersed in the same concentration as that of sample D in terms of mild steel. From the microstructure, corrosion cracks dominated the surface including white deposits. However, the level of corrosion damage compared to sample D (mild steel) immersed in the same ethanol concentration is quite high. Thus, HT250 grey cast iron could not thrive better in this environment. The dominant elements as observed from the EDS result showed that O, Fe, N, Na and S have higher percentage by weight.

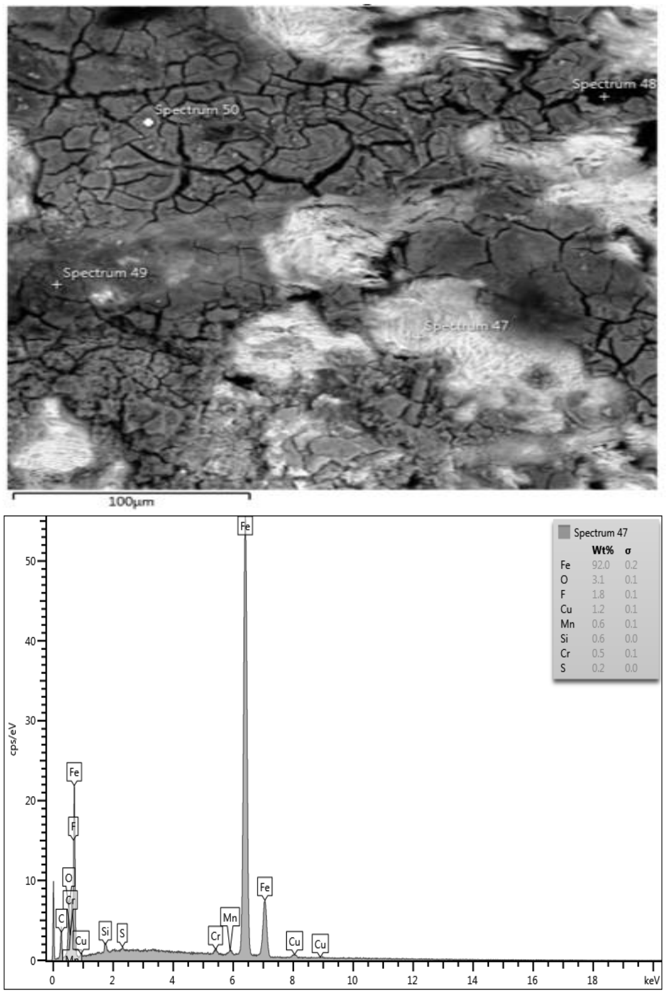
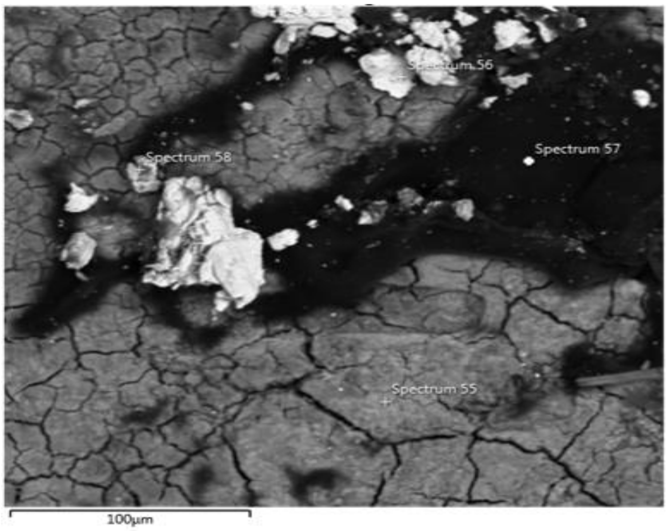


Figure 7: SEM/EDS of HT250 grey cast iron sample immersed in solution B



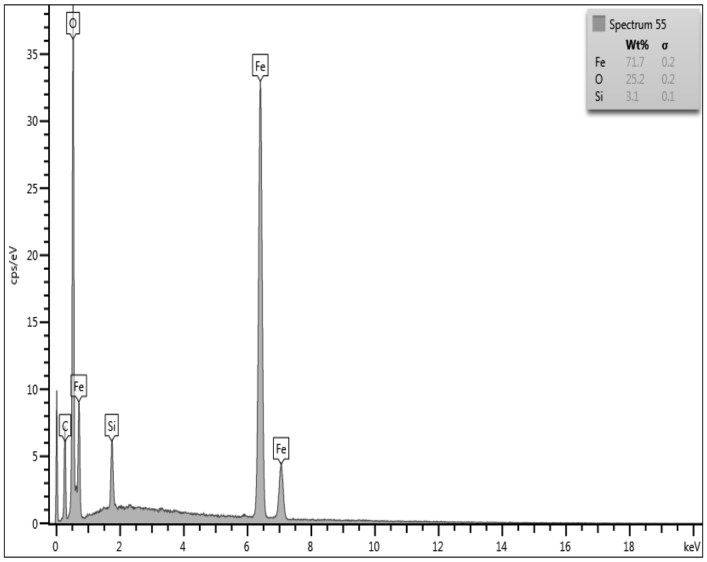


Figure 8: SEM/EDS of HT250 grey cast iron sample immersed in solution C

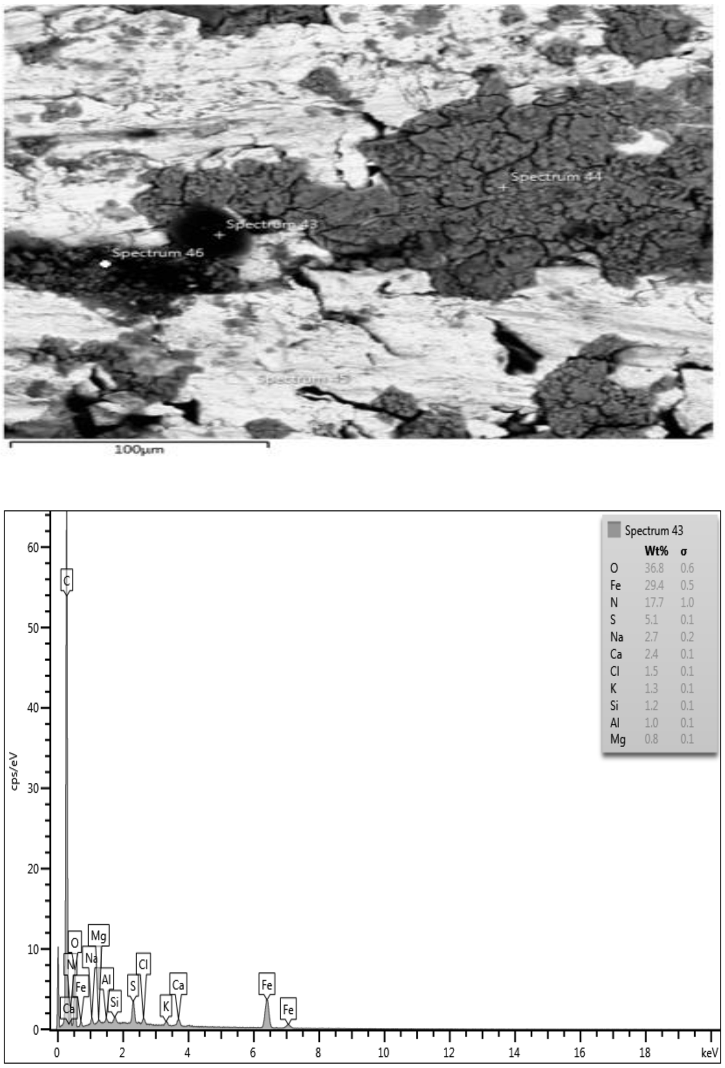


Figure 9: SEM/EDS of HT250 grey cast iron sample immersed in solution D

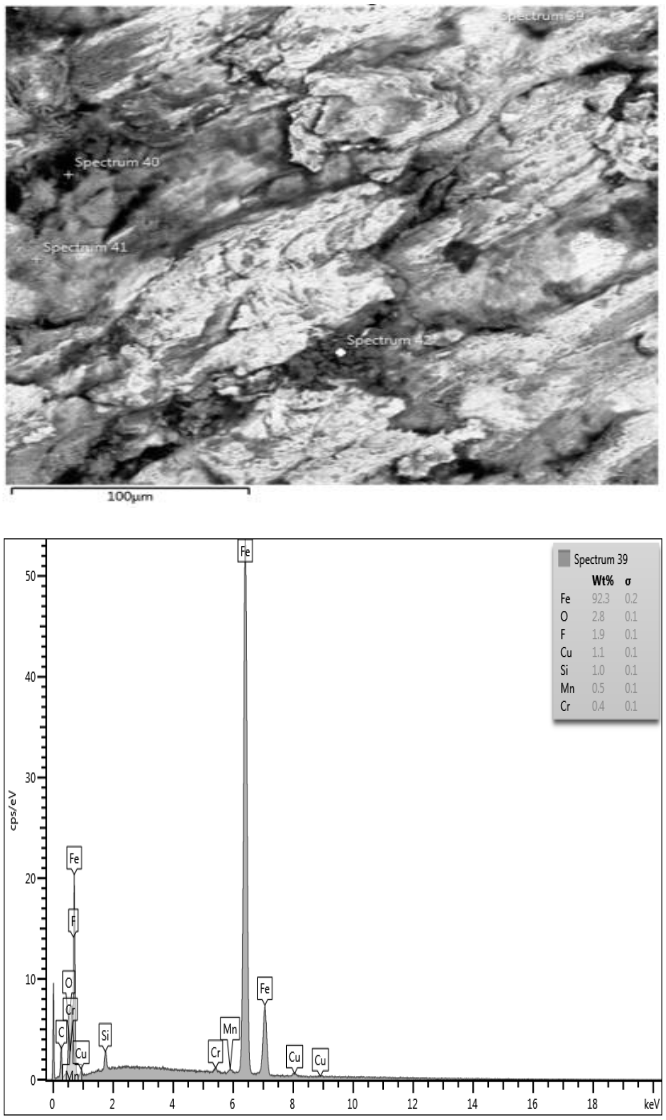


Figure 10: SEM/EDS of HT250 grey cast iron sample immersed in solution E (Distilled water) Control

Figure 10 represent the SEM/EDS microstructure of sample E immersed in distilled water as in the mild steel. It can be observed that the material white corrosion deposit dominates the surface of the material and there were no corrosion cracks as observed in that of mild steel immersed in the same medium. Thus, HT250 grey cast iron survival in distilled water show better result than that of mild steel.

IV. CONCLUSION

An extensive study of the microstructural evolution of HT250 grey cast iron and mild steel was investigated using varying concentration of blended ethanol. In addition, a review of the different failure and most importantly chemical degradation of HT250 grey cast iron and mild steel in different environmental conditions was established in this study. Results from the microstructures showed that there was microstructural damage with the evidence of corrosion deposits which appears white and dark in appearance. This is attributed to the various concentration as well as the nature of the blended ethanol. More so, the microstructural characterization revealed that the corrosion products on mild steel and HT250 grey cast iron could cause major damage in the components fabricated using this material as well as when in service environment. Results suggests that the microstructural changes provide to the material scientist the qualitative corrosion information of these materials in different environment. Conclusively, the study has enlightened the design engineers and material specialist on the need for proper material selection during engineering design.

AUTHOR CONTRIBUTIONS

E. Y. Salawu; Conceptualization and experimentation, **K. A. Shittu;** Results and Discussion, **S. A. Afolalu;** Methodology, **J. F. Kayode** and **S. L. Lawal;** Literature Review, **O. O. Ajayi;** Result analysis and discussion, **S. O. Ongbali;** Experimentation and editing.

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