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# Effects of Varying Microstructural Constituents on Corrosion Resistance: A Review

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**ABSTRACT**

Several detrimental phases usually result in materials due to improper variation and modification of the microstructural constituents. This usually cause serious defect and result in materials with poor mechanical properties as well as corrosion resistance. Majority of this problem could be traced to even the techniques of manufacturing. Thus, this study focused on a forensic review of the microstructural constituents and its how its variation affects the electrochemical performances of metals and alloys. The various types of microstructures were highlighted and their importance in several applications were explored. Furthermore, the study discussed the various methods of characterizing the microstructures of constituents and several of their mechanical properties that could have effects on the corrosion resistance were presented. Additionally, the effect of pores and composition of microstructural constituents were presented in detail. Also, it was established that it is necessary to modify microstructural constituents in a way that will improve the microstructural and corrosion behavior. The study provided potential information on the techniques of modification of the microstructural constituents that can influence the surface morphology and the mechanical properties of engineering material.

## 1. INTRODUCTION

The term microstructure is referred to as the structure which emerge after material preparation and this can be revealed using optical microscope, scanning electron microscope and transmission electron microscope etc. Depending on the material and nature of material, the highlighted microscopes have different application. Materials' microstructure like metals and polymers have strong influence in the physical and mechanical properties which include corrosion resistance, micro-hardness, ductility, toughness as well as strength. However, these microstructures are viewed nanostructured level and crystal structure level depending on the nature of the material [1]. It is worthy of note to say that the mechanical and physical properties of microstructures are attributed to the nature of defect or absence from the microstructure as well as its chemical composition [2]. More so, the defects are of varying geometries, however, the most important one is referred to as pores. Thus, different phases are exhibited by different materials. Adequate management of these materials will lead to its effective utilization [2]. In the study of Loginova et al. [3], it was reported that addition of fine constituents of municipal waste to cement mortar improved the mechanical strength like such as hardness and microstructural characteristics. Similarly, Dong and Shen [4] also reported that mechanical and microstructural properties improvement in steel material was made possible by the stability of the retained austenite during annealing process. In addition to this, Hariharan et al. [5] also corroborate the fact.

## 2. IMPORTANCE OF MICROSTRUCTURAL CONSTITUENTS

Investigation into the microstructures of constituents used in engineering analyses are necessary for a scientist or engineers to determine their structural behavior, standards and specification [6, 7]. This is one reason while theoretical design strength of engineering materials is needful to be able to achieve efficiency in real-life application. Several microstructures are identified by α and β type grains and this is also described by BCC and FCC structure [8]. Thus, within the structure of the grain, there exist defects which could be in the form of dislocation, vacancies and boundaries. Critical understanding of these features is needful in their choice of selection of materials for manufacturing [9].

For instance, in the study of Sankaran et al. [10] reported that, to understand the degradation phenomenon of a composite micro alloyed steel, an investigation of the microstructure was carried out after the fatigue test to be able to determine the strain amplitude of the sample. Furthermore, it reported that the bainite and martensite which constituted the microstructure remained stable during the experiment. However, only some portion of the bainite of the steel sample was subjected to shear stress. Hence, to harness the potentials of advanced techniques in manufacturing, an effective characterization of the microstructure is needful for sustainable manufacturing.

Currently, many researches focused on the development of composite materials that would not only provide a clean solution to engineering problems but have sustainability features. Hence, many studies are beginning to focus on the characterization of developed materials for effective applications. For instance, Travincas et al. [11] reported that mortars with fly ash, glass and rubber constituents have been developed to replace the binder which initial existed in the material and the microstructural study revealed a refined structure that is capable of maintaining sustainability. The result of the study also demonstrated the sensitivity of the developed composite to the physical properties displayed by the microstructures. In the case of composite materials like ceramic matrix composite, it is a very light weight material which perform well at a temperature of about 1000°C. However, the manufacturing process of ceramic matrix composite is highly intense and this usually lead to complexity in the resulting microstructures due to the variation in the constituents of the microstructure defects due to the processing materials.

Bulgarevich et al. [12] carried out a study on the influence of varying the microstructural constituents on the fatigue behavior of steel components. The study considered an FN0208 type of steel with a composition of 2 wt.% of Nickel and 6 wt.% of carbon. More so, different microstructural constituents were employed in the study by using two different heating techniques which are sintering-hardening and oil quenching. The result revealed hard regions or phase which reduced the effect of fatigue in the treated material. In addition to this, materials that undergo this form of heat treatment will not only achieve the needed strength and hardness, but will have consistency in their microstructures.

According to Weng et al. [13], there is a clear relationship between the evolution and orientation of in the material content of a microstructure. Thus, it is noteworthy to say that this relationship has a significant influence on the mechanical properties of dual phase materials and the techniques of measuring the microstructure of an anisotropic elastic-plastic material remained a major challenge that several researches have not been able to solve. Most importantly, certain microstructures like inclusions, voids and stress raisers usually evolve when material is in service. This can pose a serious structural safety issues and eventual failure of the materials and process. However, in the case of continuum mechanics, it is impossible to integrate microstructures in engineering computations. Consequently, the microstructure of any material influences its physical and chemical properties ranging from corrosion, ductility, strength, toughness and hardness. These properties will equally affect the performance of the material in application which is a function of the behaviour of the constituent.

## 3. TYPES OF MICROSTRUCTURAL CONSTITUENTS IN STEELS

Microstructural constituents in steels vary in types and structure which includes; carbides, ferrites, pearlites, cementite, martensite, bainite and tempered martensite. The choice of size, shape and grain distribution of these constituents are quite important in industrial/material manufacturing process. for instance, iron is known to have a body cubic structure (B.C.C) at ordinary temperature. Also, the B.C.C structure is known to have an amorphous region which is characterized by high thermal stability and curie temperature which identifies the grain boundaries and this is what contributes to the softness in the magnetic properties.

However, it is known to be ferromagnetic at 768°C. The magnetic phase is referred to as alpha-iron (α-iron) and non-magnetic phase as beta-iron (β-iron). On heating to about 910°C, iron transform into face centered cubic (F.C.C) with symbol (γ) and return to B.C.C (δ) after cooling to about 1400°C. This is what is referred to as allotropic transformation in iron. Hence, it is important to understand this these changes and their application in several manufacturing processes [14].

a) Ferrite refers to the carbon/alloying elements with a B.C.C structure. It is known to be the softest among the phases of steel. Figure 1 showed the microstructure of ferrite.

b) Pearlite is a product of austenite that results from eutectoid decomposition. In most cases, its hardness depends on the interlamellar spacing which is a function of the cooling. Figure 2 represent a pearlite microstructure.

c) Martensite results due to the quenching of steel in a rapid manner. Figure 3 showed martensite results from austenite without any diffusion mechanism. The hardness is always a function of the carbon content. Thus, its ductility depends on the decrease in carbon and this is the reason why there is brittleness in medium and high carbon steel.

d) Cementite is one of the microconstituent in the eutectoid steel. It is hard and brittle due to its grain boundaries as well. It formed a better phase in hypereutectoid steels. Figure 4 showed the microstructure of cementite.

e) Tempered martensite refers to the product of steel that was reheated below a particular temperature after being quenched to restore the lost toughness. It is usually carried out in different phases depending on whether the steel is a is an alloy or plain carbon steel.

A study by Scherbring et al. [15] reported that austenite and ferrite are two important phases can that can improve the strength of a duplex stainless steel. In other word, yield strength and hardness is increased in duplex stainless steel in the presence of ferrite constituents even when compared to the austenite. Also, addition of nitrogen to duplex stainless steel stabilizes the austenite, improve the strength and pitting corrosion resistance. However, nitrogen is considered to have high solubility at austenite stage.

Furthermore, in the field of additive manufacturing, the use of constituents is completely different when compared to wrought iron. For instance, in the additive manufacturing of titanium, findings established that products are better in terms of mechanical properties than the ones manufactured via the conventional methods. Especially, those manufactured using laser techniques. They have been known to have higher yield strength and reduced ductility due to the martensite formation resulting from raped cooling. Thus, microstructural control is possible via additive manufacturing techniques [16].

In addition to the aforementioned constituents which affects the microstructural constituents of the steel, it is important to know that all mechanical properties ranging from strength, hardness, creep and toughness are being affected by the grain boundaries. In other word, grain structure, growth and recrystallization are features which affect the properties of a microstructure. These features make the selection of materials very important, i.e. is its suitability for manufacturing. Figures 1-4 showed the various microstructures as discussed earlier. However, in the aspect of the type of constituent that will have severe corrosion effect, it is important to say that corrosion effect is determined by the uniformity of the constituent microstructure as earlier stated in several studies.

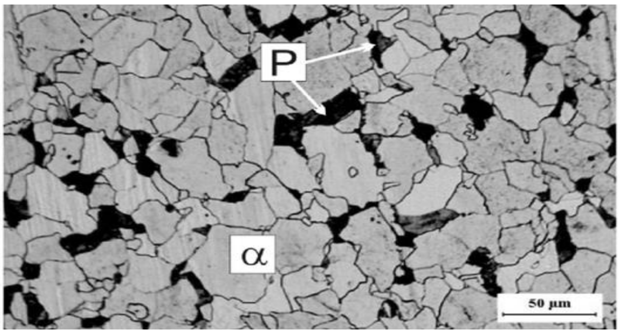


**Figure 1.** Optical micrograph of ferrite-pearlite of steel
Source: [10]

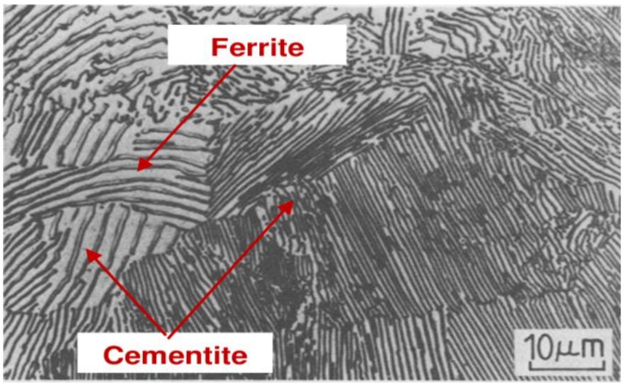


**Figure 2.** Microstructure of pearlite (lamellar mixture of ferrite and cementite)
Source: [17]

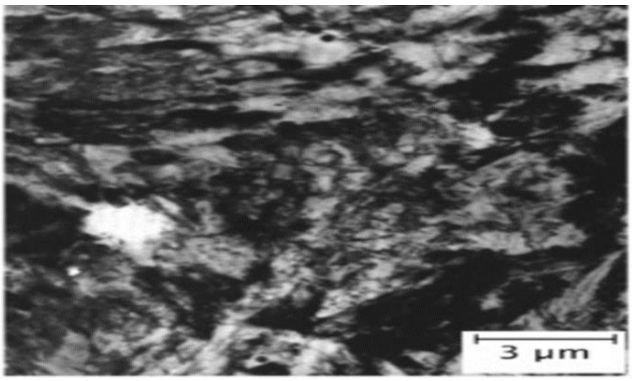


**Figure 3.** Microstructure of granular bainite
Source: [18]

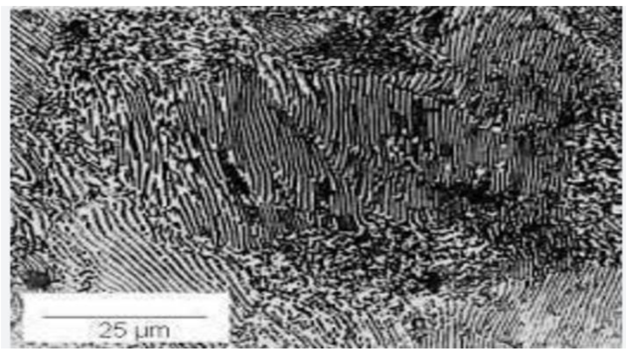


**Figure 4.** Microstructure of cementite
Source: [19]

## 4. MICROSTRUCTURAL CONSTITUENTS AND PROPERTIES

Several microstructural constituents have been used in the improvement of mechanical properties of metals such as strength, toughness, wear and hardness. For instance, the demand of materials with high-toughness and strength by the ship building industry, oil and gas, heavy machineries have necessitated the modification of constituents for developing super hard alloys. In the study of low carbon bainitic steel, it was reported that the martensite-austenite constituent improved the tensile strength of the bainitic steel.

Also, it was further reported that increase in the size of the martensite-austenite constituents resulted in the crack initiation at the interphase between the martensite-austenite constituent phase. However, deploying a constituent size of below 1 μm resulted in the improvement of toughness. Thus, a great relationship existed in the microstructure, processing parameters and the mechanical properties of developed materials [20].

In the field of artificial intelligence, it has been demonstrated that there is possibility of classifying and clustering constituents that will provide the best mechanical properties for a specific application using some statistical techniques and machine learning approach. That is categorizing and use of pattern recognition techniques will provide a sustainable solution for the production an excellent microstructure. It is possible to categorize pearlite/ferrite and ferrite/pearlite/bainite constituents using machine learning and other algorithms [21].

It was reported by Holm et al. [22] that the microstructural constituent quantification involves the use of ingenuity in a scientist to decide on what to measure and how to measure it using the available techniques. However, the advancement in computer vision had led to smart approach in the extraction of microstructural information. This is possible via the use of machine learning and several algorithms.

A study by Awale et al. [23] revealed that application of M23C6 constituent in the heat treatment of P91 steel resulted in variation in the sizes of the constituent and this variation caused an excellent variation in the strength of the steel. For Al7075, it contains iron and silicon constituents that contribute in deformation during fatigue loading. Thus, to understand these constituents, the porosity, size and distributions are very important. Hence, constituent properties are better predictor of the mechanical behavior of most binders.

Due to the importance of the properties of microstructural constituents, it was possible to predict the ultrasonic velocity of ternary oxide glasses via artificial intelligence approach. There exists a complex relationship between the microstructural properties and the properties of the chemical constituents. Since artificial neural network is an adaptive technique that can capture the complexities and the non-linear relationship using the input as the microstructural constituents [24].

According to Pham and Nguyen [25], nanoindentation is a useful tool in the analyses and identification of the microstructural constituent phases in steel. This is made possible due to the heat during welding which usually results in the transformation of the microstructural phases and result in the improvement and hardness of the phases.

Interestingly, there seem to be less attention on what the microstructure depends on before it can be selected for a particular application. This aspect is important in sustainable building of materials, structures and machineries. The finer the constituent, the easier the compaction and binding with other additives. An example is building of pavement in road construction and use of recycled plastic materials as a constituent in road construction. Also, buildings walls of structures. It worthy of note to say that microstructure does not depend on the composition only, but strong understanding of the mobility of the atoms and the concentration gradient are equally important. In addition, energy required in the formation of phases is equally important in the analyses of the microstructural constituents [25].

## 5. CHARACTERIZATION OF MICROSTRUCTURES

To modify and develop a robust material for a suitable engineering application, there is a need to characterize the morphological and the material properties of such chemical compositions and mechanical properties as shown in Figure 5. The processing of the images of an element offers a robust information like the presence of pores, which can cause rupture in the material as shown in Figure 6, the orientation of the material crystals, volume fractions and appearance of voids. All these features formed the morphology of the material. In the case of the material properties, nanoindentations will equally reveal if the material is homogenous or heterogeneous in terms of the distributions as shown in Figure 7.

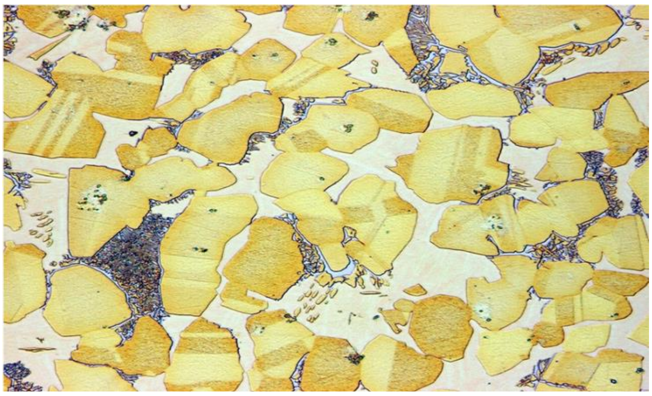

**Figure 5.** Metallography of alloys
Source: [21]

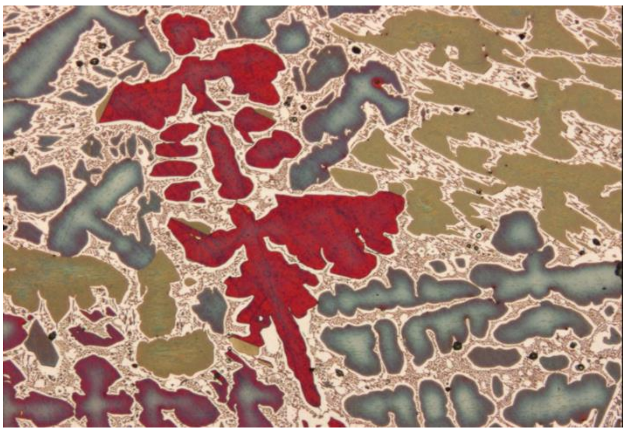

**Figure 6.** Micrograph of bronze showing a dendritic structure
Source: [12]

The nanoindentation technique is ideal for testing nanoscale thin films and materials, as it can limit the indentation depth to reduce the substrate effects. This property is particularly helpful when testing on materials coated with films or when testing on heterogeneous materials. The effect of nanoindentation depends on the material distribution which is either heterogeneous or homogenous. Another of characterizing microstructures is in the use of statistical techniques where statistical models are used to extract complex properties from the images like scanning electron microscope or optical microscopy. Example is one-point correlation function which defines the probability of random points on the phase of the microstructure.

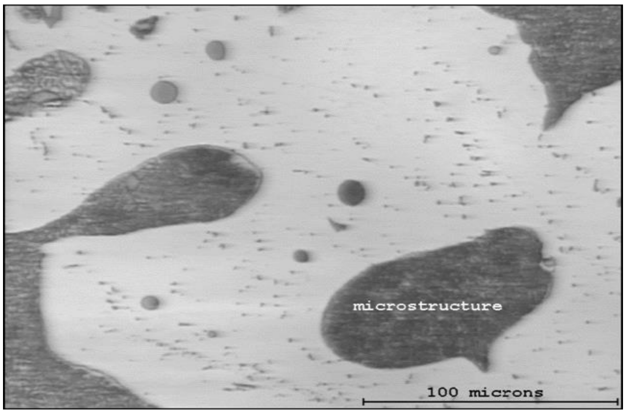


**Figure 7.** Morphology of AlSi
Source: [26]

## 6. INFLUENCE OF MICROSTRUCTURAL CONSTITUENTS ON CORROSION RESISTANCE

Underlying reasons for corrosion performances of several materials have been studied using different equipment like scanning electron microscope (SEM), transmission electron microscope (TEM) and optical microscopy. However, Particle size and density have been found to be major factors that affect the corrosion performance of most metals as often revealed by the test equipment. For instance, magnesium alloy was reported to have better corrosion resistance after laser treatment. Also, localized corrosion changed to uniform corrosion as a result of the laser treatment while increase in the size of thick mixed metal oxide was recorded as well [18]. Thus, microstructural basis formed the fundamentals of corrosion study.

Integration of akermanite particles into magnesium as a binding agent revealed a newly developed magnesium composite with excellent corrosion resistance and strong biocompatibility due to the binding agent a (akermanite). The refinement of the reinforcing agent resulted in excellent mechanical property [26]. Addition of silicon to AlNiYCo was reported to have improved the pitting corrosion resistance and thermal stability [27]. Furthermore, it was reported that silicon addition to the alloy also caused a stable and consistent amorphous multialloy. Dai et al. [28] examined the improvement in the corrosion of Mg-Gd-Ni alloy by tailoring the microstructural constituent using volume fraction of long period stacking order (LPSO) phase. The result showed that there was increase in the corrosion rate with increasing volume fraction as well. This can equally be attributed to the change from the continuous to discontinuous phase of the LPSO phase. Thus, it is possible to say that corrosion propagation path was created which caused an increased galvanic corrosion especially with alloy of Mg-Gd-Ni with high LPSO. Thus, the increasing interest in additive manufacturing requires the need for study of corrosion properties of alloys.

Guo et al. [29] investigated the evolution of Si3N4/316L microstructure using AgCuTi/Ag filler as constituents. Corrosion study was carried out to understand the relationship between the microstructure and the corrosion characteristics at the joint. The results showed that stress was relieved at the joint of the Si3N4/316L due to the addition of AgCuTi/Ag composite filler. Furthermore, there was change in the pitting corrosion exhibited by Cu to uniform corrosion of the 316L. Thus, the interphase of seam/316L was observed to exhibit corrosion behavior as revealed by the SEM image, Hence, microstructural constituents are strong influencers of material corrosion.

Assessment of Cr-Mn, Cr-Ni and super austenitic Cr-Ni-Mo-Cu stainless steels in a 3.5% NaCl via open circuit potentials, potentiodynamic polarization and electrochemical impedance revealed the presence of austenitic structure in super austenitic structure with about 10% ferrite present in Cr-Ni. In addition to this, it was observed that refined grain boundaries ranginging from austenite and martensite phases were found in the Cr-Mn stainless steel. In the same vein, the corrosion Cr-Ni-Mo-Cu stainless steel exhibited a better corrosion resistance as well as higher passivation compared to Cr-Mn and Cr-Ni. This could be associated with the presence of high content of Mn, Cr, Ni and Mo. These elements are strong agents, which have high aggression to Cl-ions [30].

Murty [31] investigated the corrosion resistance of a homogenized microstructure of a high entropy alloys of FeCoCrNiCu using carbon nanotube constituents. The mixture was administered in varying percentage weight of 0.1, 0.2, 0.5, 1.0, 1.5, 2.0, 3.0, 5.0, 7.0 of carbon nanotubes and spark plasma sintering technique was applied at 800℃. The result showed that there was decrease in corrosion rate with the addition of the carbon nanotube constituents up to 2 wt.%. More so, it was further observed that the excellent improvement in the corrosion performance could be attributed to the homogeneity in the chemical composition. It has been established that a promising material that can be used for protecting hot-end systems in aerospace engines is lanthanum-cerium. However, it was also reported to have a major bottle neck which is its hot corrosion resistance to $Na_2SO_4+V_2O_5$. The integration of Nb as a constituent element would definitely stabilize and increase the strength of the corrosion resistance. More so, the addition of Nb when compared with the other constituent elements, was observed to provide supporting effect for crystals. These findings help in excellent design of high-entropy thermal barrier coatings for aerospace engines.

Similarly, addition of Nb to a synthesized high entropy alloy of CoCrFeNiNbx revealed that there was a change in the microstructure from single face to a duplex face centered cubic. Also, it was reported that Nb addition caused the alloy to exhibit a hypoeutectic structure and it also caused and improved yield strength as well as fracture strength [32].

In the field of energy storage system production, microstructural constituents have been reported to play a significant role in improving the corrosion resistance and improving the reliability of the storage system. For instance, battery manufacturers have succeeded in the optimization of the manufacturing processes and chemical properties of the microstructural constituents [19]. This idea will not just reduce the production cost of battery cells, but reduce the weight, improve the battery and corrosion resistance. For instance, addition of cellular and dendritic structures of Pb-Sb alloys revealed that there was reduction in corrosion rate in that of the cellular microstructural with increasing spacing in the structure. However, a refined microstructure was observed in that of the dendritic microstructure with a better corrosion performance [17]. Thus, it is worthy of note to say that the advancement in the energy storage systems relied heavily on the modification of microstructural constituents. These constituents eventually influenced the corrosion resistance of the system [33].

## 7. CONCLUSION

A forensic review on the effects of microstructural constituents on corrosion resistance of engineering materials have been carried out. From the review it was established that microstructural constituents varies in types, sizes and grain growth as well as mechanical properties such as hardness, strength, toughness etc. these variations in their properties has been reported to be responsible for strength and toughness in materials.

Similarly, the variations have helped material engineers on the modifications to suit several applications. Thus, it is possible to develop novel materials especially that of high entropy alloys and super hard alloys capable of operating at elevated temperature. Furthermore, the variation in the microstructural constituents have helped the understanding of the nature and type of environment for survival.

Thus, there exist several formulations and techniques for the modifications of several materials to form alloys that can be used for several applications. However, the study has also established that pores and elemental compositions are strong influence which microstructural constituents in materials. For instance, presence of pores, unless required will serve as strong regions for rupture, in most cases for a fully developed material, they are referred to as stress raisers. It forms a strong point for initial crack and this propagate into larger cracks and overtime, fatigue ensue to cause final rupture or failure of the material. That is why the phase diagrams of many materials are important during characterization. Thus, modification of the material properties will help in improving the corrosion resistance performance.

## REFERENCES


[1] Mariappan, K., Nagesha, A., Vasudevan, M., Bhaduri, A. K. (2022). Characterization of the cyclic deformation behavior of simulated HAZs and other constituent microstructural regions of P91 steel weldment. International Journal of Fatigue, 164: 107118. https://doi.org/10.1016/j.ijfatigue.2022.107118

[2] Gsellmann, M., Scheiber, D., Klünsner, T., Zálešák, J., Zhang, Z., Leitner, H., Romaner, L. (2022). Bond strength between TiN coating and microstructural constituents of a high-speed steel determined by first principle calculations. Acta Materialia, 222: 117439. https://doi.org/10.1016/j.actamat.2021.117439

[3] Loginova, E., Schollbach, K., Proskurnin, M., Brouwers, H.J.H. (2023). Mechanical performance and microstructural properties of cement mortars containing MSWI BA as a minor additional constituent. Case

Studies in Construction Materials, 18: e01701. https://doi.org/10.1016/j.cscm.2022.e01701
[4] Dong, X.X., Shen, Y.F. (2022). Improving mechanical properties and corrosion resistance of 0.5 wt.% C TRIP steel by adjusting retained austenite stability and microstructural constituents. Materials Science and Engineering: A, 852: 143737. https://doi.org/10.1016/j.msea.2022.143737
[5] Hariharan, A., Goldberg, P., Gustmann, T., Maawad, E., Pilz, S., Schell, F., Gebert, A. (2022). Designing the microstructural constituents of an additively manufactured near β Ti alloy for an enhanced mechanical and corrosion response. Materials & Design, 217: 110618. https://doi.org/10.1016/j.matdes.2022.110618
[6] Bhagyaraj, J., Mukherjee, S., Sangal, S., Mondal, K. (2022). Enhancement of mechanical properties and corrosion resistance of bainitic elastic rail clip (ERC) with finer microstructural morphology. Materials Today Communications, 33: 104425. https://doi.org/10.1016/j.mtcomm.2022.104425
[7] Wu, W., Qin, L., Cheng, X., Xu, F., Li, X. (2022). Microstructural evolution and its effect on corrosion behavior and mechanism of an austenite-based low-density steel during aging. Corrosion Science, 212: 110936. https://doi.org/10.1016/j.corsci.2022.110936
[8] Xu, X., Lu, H., Qiu, J., Luo, K., Su, Y., Xing, F., Lu, J. (2022). High-speed-rate direct energy deposition of Fe-based stainless steel: Process optimization, microstructural features, corrosion and wear resistance. Journal of Manufacturing Processes, 75: 243-258. https://doi.org/10.1016/j.jmapro.2021.12.026
[9] Anijdan, S.M., Sabzi, M., Park, N., Lee, U. (2022). Sour corrosion performance and sensitivity to hydrogen induced cracking in the X70 pipeline steel: Effect of microstructural variation and pearlite percentage. International Journal of Pressure Vessels and Piping, 199: 104759. https://doi.org/10.1016/j.ijpvp.2022.104759
[10] Sankaran, S., Madhavan, R., Suwas, S., Ray, R.K., Padmanabhan, K.A. (2022). Microstructural evolution and stability during strain-controlled fatigue in a multiphase microalloyed steel. Materials Science and Engineering: A, 861: 144382. https://doi.org/10.1016/j.msea.2022.144382
[11] Travincas, R., Pereira, M.F., Torres, I., Maurício, A., Silveira, D., Flores-Colen, I. (2022). X-ray Microtomography applied to mortars: Review of microstructural visualization and parameterization. Micron, 164: 103375. https://doi.org/10.1016/j.micron.2022.103375
[12] Bulgarevich, D.S., Tsukamoto, S., Kasuya, T., Demura, M., Watanabe, M. (2019). Automatic steel labeling on certain microstructural constituents with image processing and machine learning tools. Science and technology of advanced materials, 20(1): 532-542. https://doi.org/10.1080/14686996.2019.1610668
[13] Weng, H., Luo, C., Yuan, H. (2022). ANN-aided evaluation of dual-phase microstructural fabric tensors for continuum plasticity representation. International Journal of Mechanical Sciences, 231: 107560. https://doi.org/10.1016/j.ijmecsci.2022.107560
[14] Mahler, M., Po, G., Cui, Y., Ghoniem, N., Aktaa, J. (2021). Microstructure-specific hardening of ferritic-martensitic steels pre and post 15 dpa neutron irradiation at 330℃: A dislocation dynamics study. Nuclear Materials and Energy, 26: 100814. https://doi.org/10.1016/j.nme.2020.100814
[15] Scherbring, S., Chen, G., Veltel, B., Bartzsch, G., Richter, J., Vollmer, M., Mola, J. (2022). Microstructural constituents and mechanical properties of low-density Fe-Cr-Ni-Mn-Al-C stainless steels. Materials, 15(15): 5121. https://doi.org/10.3390/ma15155121
[16] Toyserkani, E., Sarker, D., Ibhadode, O. O., Liravi, F., Russo, P., Taherkhani, K. (2021). Metal additive manufacturing. IoP 12( 20): 1001.
[17] Kapito, A., Mostert, R.J., Stumpf, W.E., Siyasiya, C.W. (2019). Carbide-free bainitic steels for rail wheel applications. In IOP Conference Series: Materials Science and Engineering, 655(1): 012012. https://doi.org/10.1088/1757-899X/655/1/012012
[18] Jana, S., Olszta, M., Edwards, D., Engelhard, M., Samanta, A., Ding, H., Rohatgi, A. (2021). Microstructural basis for improved corrosion resistance of laser surface processed AZ31 Mg alloy. Corrosion Science, 191: 109707. https://doi.org/10.1016/j.corsci.2021.109707
[19] Osório, W.R., Rosa, D.M., Garcia, A. (2008). The roles of cellular and dendritic microstructural morphologies on the corrosion resistance of Pb–Sb alloys for lead acid battery grids. Journal of Power Sources, 175(1): 595-603. https://doi.org/10.1016/j.jpowsour.2007.08.091
[20] Lan, H.F., Du, L.X., Misra, R.D.K. (2014). Effect of microstructural constituents on strength-toughness combination in a low carbon bainitic steel. Materials Science and Engineering: A, 611: 194-200. https://doi.org/10.1016/j.msea.2014.05.084
[21] Müller, M., Britz, D., Ulrich, L., Staudt, T., Mücklich, F.. (2020). Classification of bainitic structures using textural parameters and machine learning techniques. Metals, 10(5): 630. https://doi.org/10.3390/met10050630
[22] Holm, E.A., Cohn, R., Gao, N., Kitahara, A.R., Matson, T.P., Lei, B., Yarasi, S.R. (2020). Overview: Computer vision and machine learning for microstructural characterization and analysis. Metallurgical and Materials Transactions A, 51(12): 5985-5999. https://doi.org/10.1007/s11661-020-06008-4
[23] Awale, D.D., Ballal, A.R., Thawre, M.M., Vijayanand, V.D., Kumar, J.G., Reddy, G.P. (2020). Microstructural investigation and mechanical properties evaluation using miniature specimen testing of various constituents of dissimilar weld joint. Journal of Nuclear Materials, 532: 152048. https://doi.org/10.1016/j.jnucmat.2020.152048
[24] Arulmozhi, K.T., Sheelarani, R. (2012). Prediction of ultrasonic velocities in ternary oxide glasses using microstructural properties of the constituents as predictor variables; Artificial Neural Network (ANN) approach. Scientia Iranica, 19(1): 127-131. https://doi.org/10.1016/j.scient.2011.11.041
[25] Pham, T.H., Nguyen, N.V. (2021). Mechanical properties of constituent phases in structural steels and heat-affected zones investigated by statistical nanoindentation analysis. Construction and Building Materials, 268: 121211. https://doi.org/10.1016/j.conbuildmat.2020.121211
[26] Mehdizade, M., Eivani, A.R., Tabatabaei, F., Jafarian, H.R., Zhou, J. (2022). Microstructural basis for improved corrosion resistance and mechanical properties of fabricated ultra-fine grained Mg-Akermanite composites.

Materials Chemistry and Physics, 292: 126765. https://doi.org/10.1016/j.matchemphys.2022.126765
[27] Gsellmann, M., Klünsner, T., Mitterer, C., Krobath, M., Wurmshuber, M., Leitner, H., Ressel, G. (2021). Strength ranking for interfaces between a TiN hard coating and microstructural constituents of high speed steel determined by micromechanical testing. Materials & Design, 204: 109690. https://doi.org/10.1016/j.matdes.2021.109690
[28] Dai, C., Wang, J., Pan, Y., Ma, K., Peng, Y., Ren, J., Ma, Y. (2023). Tailoring the microstructural characteristic and improving the corrosion rate of Mg-Gd-Ni alloy by heat treatment with different volume fraction of LPSO phase. Corrosion Science, 210: 110806. https://doi.org/10.1016/j.corsci.2022.110806
[29] Guo, S., Sun, L., Fang, J., Zhang, J., Zheng, Z., Liu, C., Shan, T. (2022). Microstructural evolution and phase-dependent corrosion of Si3N4/316L joints using AgCuTi/Ag composite fiols. Materials Characterization, 193: 112270. https://doi.org/10.1016/j.matchar.2022.112270
[30] Sheik, S., Tirumalla, A., Gurrala, A.K., Mohammed, R. (2022). Effect of microstructural morphology on corrosion susceptibility of austenitic and super austenitic stainless steels. Materials Today: Proceedings, 66: 514-518. https://doi.org/10.1016/j.matpr.2022.06.113
[31] Murty, B.S. (2020). Microstructural homogenization and substantial improvement in corrosion resistance of mechanically alloyed FeCoCrNiCu high entropy alloys by incorporation of carbon nanotubes. Materialia, 14: 100917. https://doi.org/10.1016/j.mtla.2020.100917
[32] Liu, W.H., He, J.Y., Huang, H.L., Wang, H., Lu, Z.P., Liu, C.T. (2015). Effects of Nb additions on the microstructure and mechanical property of CoCrFeNi high-entropy alloys. Intermetallics, 60: 1-8. https://doi.org/10.1016/j.intermet.2015.01.004
[33] Martín, S.D., Cock, D.T., García-Junceda, A., Caballero, F.G., Capdevila, C., de Andrés, C.G. (2008). Effect of heating rate on reaustenitisation of low carbon niobium microalloyed steel. Materials Science and Technology, 24(3): 266-272. https://doi.org/10.1179/174328408X265640