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Overview of the impact of heat treatment methods on corrosion performance of metals and alloys

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Abstract. The increasing demand for high entropy alloys and the need to develop high-strength steels for structural applications has led to the various applications of heat treatment in the metallurgical field. However, numerous mechanical integrities of heat treatment must be satisfied to ensure that the desired property is not only obtained but also achieved sustainably even while the material is under the application in a degraded environment. Thus, the study did an extensive review of the different heat treatment methods and their benefits. The study discussed the purpose of heat treatment, types of heat treatment, and their effect on the corrosion behaviour of the substrate. This provides potential information on the basics of heat treatment to further understand its impact on the corrosion performance of engineering materials.

1 Introduction

1.1 Heat treatment

Heat treatment is a process of modifying the metallurgical properties of materials to make the suitable for a particular application. The characteristics of materials that are usually altered during heat treatment include toughness, strength, hardness, and ductility. However, a great aspect of heat treatment is that the desired properties of the material must be achieved safely without causing problems or failure to the material [1]. In most cases, the desired properties would have been simulated during the modification to quantify the benefits to the material.

Heat treatment is very important in determining the reliability of a material or component. For instance, some industries carry out heat treatment on their pipes to prevent cracks and stress. This is because stress and cracks would form a major failure in the materials as well

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as the components. Thus, there is a need to stress relieve the material before deploying them into the manufacturing system [2].

A typical example of an industry where heat treatment is used is in the oil and gas companies where heat treatment techniques are used to relieve residual stresses on welded pipes especially, the materials that operate in cracking regions. Steel parts and alloys change their physical, chemical, and mechanical properties via heat treatment. Thus, helps in making the manufacturing process as easy as possible.

The result of the change in the mechanical properties of steel will make the final product more effective by resisting wear and tear during application [3]. The choice of heat treatment method depends on the desired properties needed for the material's application. It is important to do adequate research to understand the difference between the techniques and the respective product required. Typical examples of heat treatment are carburization, case hardening, tempering of steel, oil quenching, and vacuum heat treatment, etc. it is worthy of note to say that any of the heat treatment techniques will cause an enormous change in the physical and mechanical properties of the material, however, the result of adequate heat treatment would produce stress relieved material that causes ease of machining and weld [2].

While heat treatment does not only increase the hardness property of steel, it as well softens it and makes it possible for certain operations to be carried out which include cold drawing and deep drawing. It produces ductile and tougher materials as well [3]. In short, heat treatment has the following advantages to metals; durable materials are produced, stronger and tougher materials, ease of machining, increased flexibility, wear-resistance increase, and overall; reliability and productivity of the material.

While heat treatment is important, studies have established that post-heat treatment is also important in the additive manufacturing industries to further offer more stress relief to the final product. For instance, Li et al. [4] investigated post heat treatment of Inconel 718 which was fabricated via rolling and integrated laser deposition technique. The material was heat treated at 1080oC for about ten (10) minutes and the heat treatment was done in a homogenous manner. The result showed that there was a dissolution of the lave phase which resulted from the rolling process and a homogenous recrystallized structure was achieved [5].

Furthermore, high precipitates of refined structure existed in the microstructure which was found to increase the yield strength and ductility of the material. Bisht et al. [5] investigated the effect of heat treatment on the mechanical behavior of SLM Al-Si alloy. The heat treatment carried out for different samples of Al-Si alloy such as direct ageing, as-built, and T6 heat treatment showed that the as-built samples exhibited the highest yield and tensile strength with less ductility. However, an increase in temperature was observed to have a significant effect on the ductility and strength. Also, a decrease in microhardness was observed for an increasing temperature of heat treatment. Additionally, the heat treatment influences the morphology of the material with improvement in hardness, fatigue life, and yield strength [6].

Heat treatment has a significant impact on the corrosion rates of metals and their alloys. For instance, according to Xiao et al. [6] heat treatment of 316L stainless steel material exhibited improved corrosion resistance of thick and thin oxide layers. However, it was observed that the thin inner layer exhibited better corrosion resistance. Zhang et al. [7] investigated the effect of heat treatment on the microstructural properties and corrosion behavior of PDF-LB Ti6Al4V. The material was heat treated between temperature ranges of 320 oC – 1020 oC. the result of the microstructural analyses showed a precipitate of alpha and beta-phases. More so, it was reported that the electrochemical results indicated that the existence of the alpha and beta phases caused galvanic corrosion to occur on the heat-treated material [7].

He et al. [8] established that there was a significant change in the microstructure and corrosion behavior of 316L stainless steel manufactured using a hybrid additive manufacturing technique. The microstructure exhibited dendritic ferrite and austenite patterns of grains. More so the annealing of the material within the temperature of 650 to 1200 °C caused irregular behavior in the corrosion rate as an increase-decrease and increase were observed in the fuel cell environment. It was further reported that the annealing at a temperature of 1050 °C caused the δ-ferrite to be changed to σ-phase having increased content of chromium and molybdenum. The presence of these elements caused an increase in the stability of the passivation film in the stainless steel, thus, superior corrosion resulted [4]. Electromagnetic-assisted heat treatment of aluminium2024 alloy revealed variations in the corrosion behavior of the samples which were divided into A, B, and C. The result of the characterization indicated that sample C exhibited increased strength while sample A has increased elongation and exhibited corrosion resistance as well. The microstructural behaviors revealed indicated that phases are mainly precipitates with enhanced with. The formulation in this study is helpful in the development of Al-Cu-Mg alloys [7].

2 Heat treatment methods and their effects on corrosion behaviour of metal alloys

2.1 Annealing

The term annealing refers to the heating of metal above the critical temperature and the cooled slowly until the final desired temperature is reached. This process is important as the metal gets softened, ductile, and tough. Thus, making it more machinable especially in a cold working process, another important purpose of annealing is that it helps in relieving stress such that the plastic deformation is removed during the recrystallization of the process.

Various annealing processes exist which include; full, partial, and final annealing. Annealing of materials or products could cause several variations in the corrosion rate. For instance, Velashjerdi, Soleymani et al. [9] developed a 316L stainless steel using sol-Gel and screen plasma annealing techniques. The annealing was done between 300-500 oC. The results showed that the plasma annealing caused a formation of nanostructure with increased crystallites and there was uniformity when compared to the traditional annealing method. However, the result of the electrochemical study showed the corrosion resistance was significant when compared to the conventional annealing method. This result also verifies that titanium oxide coating can reduce the corrosion rate of stainless steel by eight times [9].

A study by Marzo et al. [10] reported structural relaxation has a great impact on corrosion performance. The study investigated an amorphous alloy (Fe78−xSi13B9Cr(x=3,4,7) by considering a change in enthalpy and curie temperature. The result showed that the curie temperature alloy increases after relaxation without a noticeable change in enthalpy. This change affected the electrochemical behavior of the heat treat treated materials. There was an improvement in the corrosion potentials which made it to be classified as a durable material [9].

Ding et al. [11] investigated the effect of annealing heat treatment on Ti6Al4V alloy developed via additive manufacturing method and subjected the alloy to electrochemical study in about 3.5 % NaCl solution. The result revealed that there was an improvement in the corrosion resistance of the developed alloy. The corrosion resistance improvement was traced to the effect of the annealing heat treatment that was done after the fabrication of the alloy. Also, it was validated by the finer crystal sizes and weakening of the texture of the alloy, this is one reason for the corrosion resistance performance [6].

In the same vein, the corrosion behaviour of CoCrFeNiW alloy was investigated in 3.5 % NaCl after annealing heat treatment to determine its corrosion resistance. In this study, the microstructure of the alloy was carefully altered using annealing heat treatment under the temperature range of 600-1200oC for about three (3) hours [8]. According to the result, after the temperature of 1000oC, the microstructure was observed to be characterized by a needle-like precipitate of μ. In addition to this, the alloy was observed to demonstrate excellent corrosion resistance in the degradation environment. Thus, the study provided great potential in the analysis of the microstructural evolution and the corrosion behavior of high entropy alloys [12].

2.2 Normalizing

This type of heat treat treatment is used in relieving the internal stresses which occurred in welding, casting as well as quenching processes. Metals are heated to a temperature of 40oC beyond their upper critical temperature which is usually above the temperature for the annealing and hardening process [9]. it is held for a particular time and cooled in the natural air. Normalized materials exhibit uniform grain sizes and chemical composition throughout the entire region of the material. Steel products under normalized processes usually appear stronger and harder in most cases. Thus, structural parts that support external load and stresses must be normalized [11].

According to Chen et al. [13] 9Cr alloy has potential applications in the marine environment because of its high corrosion resistance, however, despite this characteristic, the corrosion resistance is possible due to the addition of Mo, Cr, and Ni in varying weight by percentage. These elements contribute to the passive film formed on the surface of the steel, especially in concrete, especially the chromium which enhances the inner passivation layer. Thus, the accumulation of the added elements served as corrosion inhibition after the breakdown of the passivation [12].

Further to this, Al is a low alloying element that can inhibit corrosion and is cheap and readily available. However, it is rich in particles that can form oxides on the layer of the material, especially in a chloride environment. This major gap is yet to be explored. Based on this problem, the study examined the behavior of aluminium in a chloride environment after heat treatment using a potentiodynamic polarization route [13]. The result showed a promotion of Al2O3-rich integrated with AlN. This caused a drastic drop in pitting corrosion at the initial stage. Thus, the mechanism of corrosion resistance variation with normalizing heat treatment has been understood. Zhang et al. [14] changed the brittleness of AlCoCrFeNi alloy via a normalizing heat treatment method to modify its mechanical properties. The result showed that normalizing heat treatment was better than quenching in water and this can increase the application of the high entropy alloy in a different environment. Villavicencio et al. [15] examined the combined role of different heat treatment treatments on the corrosion behavior of API5LX42 steel in a chloride environment. Aluminium oxide particles were obtained and identified as rolled, annealed, normalized and tempered, and quench-tempered respectively.

The different heat treatments transformed the aluminium oxide in X42 steel in a pattern of annealed, normalized, quenched, and quench-tempered with the average value of 0.15,0.15, 0.12, and 0.07 percent respectively, while the as-rolled has an average of 0.85 percent. The result showed that the presence of the aluminium oxide accelerated pitting potentials. More so, there was variation in the corrosion rate of samples based on the various heat treatment applied. As-rolled was found to be 0.067 mm/year, annealed, 0.078 mm/year, and quench-tempered was found to be 0.103 mm/year while the normalized sample gave a corrosion rate of 0.091 mm/year [16].

Thus, corrosion resistance of quenched and quench-tempered microstructure depends on the phase’s distribution in their microstructure. Quenched samples were characterized with single-phase microstructure and this resulted in a decrease in the micro galvanic couples which resulted in the observed improvement in corrosion resistance. On the other hand, quenched with tempered samples have a two-phase microstructure which also increased the micro-galvanic cells thus reducing the corrosion resistance [11]. Thus, the variation in the distribution of the phases resulted due to the different heat treatment methods applied. Hence, the study showed that different heat treatment methods do es not only impact the microstructural evolutions of the alloy but have a serious effect on the corrosion behavior of metals and their alloys. This provided important information on the choice of appropriate heat treatment methods for different materials [13].

2.3 Hardening

This is the commonest heat treatment process used in improving the surfaces of metals. The process involves heating the metal to a particular temperature and then cooled in a medium cooled by water, brine, or oil [4]. The result of hardened steel always shows increased hardness and strength. A typical example of hardening is case hardening in which the outer layer of the sample is hardened. The process is usually applied to the shaft to protect its outer layer from excessive wear, while the core region still possesses the ability to withstand fatigue stress. Other types of hardening techniques include; induction, flame, and differential hardening [15].

In the study of das Neves et al. [16], it was reported that age hardening of AA6351 alloys and salt spraying for eight (8) hours yielded a reduced corrosion rate of the material. AA6351 material is recognized to be very important in marine applications, therefore understanding the heat treatment process is necessary because of the environment of degradation. Leo et al. [17] examined the corrosion behavior of hardened stainless steel manufactured via additive manufacturing. It was reported that the corrosion resistance improved due to the heat treatment. Furthermore, it was also observed that the corrosion performance improved for the finer grains due to the amount of austenite [12].

To understand the variation between the corrosion resistance and strength of 5XXX aluminium alloys, a novel heat-treated Al-Mg-Zn-Ag alloy was studied. The alloy was developed from non-isothermal ageing. The results indicated that there was increased age hardening and the density of the precipitate as well. More so, the increased precipitate caused a discontinuity in grain distribution which helps in the strength and corrosion resistance of the developed alloy. Thus, isothermal age hardening does not only bring microstructural evolution but improvement in the strength and corrosion of the alloy.

Christudasjustus et al. [18] investigated the effect of the age-hardening method on the corrosion of Al-5at. %V alloy which was produced using a high-energy ball mill and compaction techniques. The age-hardening was done at a varying temperatures of 150, 200, and 250 °C. from the result, the highest hardness was achieved at 150oC which occurred as a result of the grain refinement. Furthermore, the corrosion resistance of all the age-hardened aluminium alloys was superior to the as-received aluminium [17].

Similarly, Ozdemir et al. [19] examined the effect of high-energy ball milling on the corrosion performance of age-hardened aluminium alloys. The study carried out a potentiodynamic test after the alloys were produced using 0.6 M NaCl solution. The result showed a significant improvement in the pitting and protection potentials of the hardened alloys. It was reported that the corrosion resistance improvement was traceable to the presence of nanocrystalline structure, the solubility of the solid, and homogenous microstructures [19].

Precipitated hardening of magnesium alloy obtained from laser surface remelting showed an improvement in the wear and corrosion of the alloy [20]. According to Zhang et al. [21], age hardening of Al-Mg-Zn-Cu-Ag showed that there is an improvement in the microstructure and the intergranular corrosion performance especially when the hardening was done at 180 oC. The improvement in the intergranular corrosion performance was linked to the variation in the age hardening state with the solid solution state having the best intergranular corrosion resistance. In the study of Maharjan et al. [22], it was reported that the material's hardness and corrosion resistance could be improved using surface laser treatment. In most cases, the content of the phases and grain size that have variations in their thickness hardly affect the corrosion resistance. The improvement in corrosion resistance comes from the chromium-enriched oxide region, which is at the topmost layer of the steel alloy.

2.4 Ageing

This type of heat treatment method is mainly used in improving malleable materials such as yield strength. It involves the dispersion of particles into the grain structure of metals and causes a transformation in the properties of the metal [21]. Ageing process elevates the temperature to an optimum level and brings it down the temperature immediately. While some materials age at room temperature, some will age artificially at increased temperature. Thus, the best way to store natural ageing materials is to store them at a lower temperature [20].

Austenitic steel such as 308L and 309L have excellent mechanical and corrosion characteristics at normal room temperature. This can be attributed to the dual-phase structure which exists at the austenite-ferrite. These properties qualify them for application in the inner surface as cladding materials and nozzles/joints of reactor vessels. However, on exposure to water during the application, corrosion will set in with oxide layer formation on the surface. This will eventually reduce the protection ability of the weld overlay cladding as corrosion protection. Stress corrosion cracking sets in as well in the nozzle/safe-end region [23].

Based on the aforementioned problem associated with the 308 stainless steel, Lin et al. [24] investigated the corrosion resistance of a thermally aged 308L stainless steel under aerated and deaerated conditions using water. Austenite and ferrite phases were involved in the study. The results showed that there was less corrosion effect after the thermal ageing heat treatment for about 7000 h. Also, in the aerated condition, there were no corrosion effects compared to the deaerated [17]. However, there was a localized corrosion effect on ferrite/austenite boundary layers at the aerated condition. In the study of Ding et al. [24], weld joints were aged at 475oC for about 2000 h to be able to obtain spinodal decomposition in which chromium resulted caused a decrease in the stress corrosion cracking.

Direct ageing treatment of Al-Zn-Mg-Cu alloy modified with Si-Zr-Er reveal significant bi-modal grain patterns and increased tensile strength of about 465 MPa, while significant improvement was recorded in corrosion resistance and this was attributed to the high presence of the grain boundaries [25]. According to Farajollahi et al. [26], ceramics materials are usually integrated into aluminium matrix composites because of the high hardness property to improve the wear and hardness of the aliminium composites. However, ceramic particles are associated with weak bonds which usually affect the binding properties of the composites. Thus, a better option is to heat treat the reinforced composite to form intermetallic compounds [24].

To this end, the study investigated post-processing heat treatment on the microstructure and corrosion characteristics of nickel-aluminide-reinforced Al-Cu-Mg alloy coating [11]. The results revealed that there was increased corrosion resistance of the composites. The corrosion of Mg-1.19Al-0.28Ca-0.44Mn (wt%) alloy is always affected after heat treatment. This is caused by solute distribution during heat treatment. This can be minimized by reducing the nucleation effect as well as the growth of precipitate during the heat treatment of alloy [27].

In the manufacturing of welded joints, the rotary friction welding technique is the most suitable. However, corrosion and plastic deformation result. Thus, the effect of artificial and natural ageing heat treatment on the corrosion behavior of welded joints was investigated by [28]. The result revealed that there was an improvement in the corrosion behavior and tensile strength after a prolonged artificial and natural ageing heat treatment. And the corrosion behavior was observed to be uniform all through the welded joint. More so, it was observed that there was a reduction in the possibility of intercrystalline corrosion, which occasioned by the existence of gran and grain boundaries after the artificial heat treatment [28].

2.5 Stress relieving

This type of heat treatment method is mainly applicable to air bottles, parts of boilers, and accumulators. This method takes the metal to its lower critical point and applies a slow cooling process in other to relieve stresses built up during the machining, rolling, and forming process. aluminium alloys have been recognized to have a wild application due to their castability and excellent corrosion resistance [23].

However, there is a limitation in its corrosion resistance due to the presence of silicon particles and inherent porosity. Due to this problem, several methods of manufacturing methods have been deployed in the manufacturing of aluminium and alloys to reduce its limitations. Among these methods is additive manufacturing which involves using pieces (selective laser melting) with adequate mechanical properties that would have been impossible with conventional manufacturing techniques [26].

For instance, aluminium-silicon is widely used in several applications due to its excellent corrosion and mechanical characteristics. Silicon presence in coarse structures is a major issue that limits the corrosion performance of the alloy. Thus, a study by de Damborenea et al. [29] established that there was a noticeable change in the mechanical and corrosion behavior of a selective laser melting of AlSi10Mg after stress relief heat treatment was performed. Additionally, it was reported by the study that pitting corrosion was accelerated due to the increase in surface roughness. Nickel-based alloys are associated with stress corrosion cracking when deployed in the primary water coolant environment. This is due to the effect of applying stress beyond yield stress. Thus, the cracking of alloys could be associated with the cold working, stress relief level. Thus, stress relief is important in most weldments to reduce corrosion failures when in the application [29].

2.6 Tempering

This process is done to reduce excess hardness and brittleness induced during the hardening. In this case, internal stresses are relieved and this makes the metals suitable for several applications. For instance, nickel aluminium bronze having high mechanical properties is used in several applications such as the fabrication of valves, and pumps and even in some applications in the aerospace industries [13]. Several plastic deformation methods have been used to improve the mechanical properties of nickel aluminium and bronze alloy, and these methods include rolling and friction stir welding [24].

These methods are associated with varying degrees of structural defects, thus making the alloy impossible for further applications especially, the propeller. Thus, heat treatment is an alternative means of enhancing the alloy for secondary applications. Based on this, Ma et al. [30] proposed a unique aging-tempering and quenching heat treatment for nickel aluminium bronze alloy. The result revealed that high strength and ductility were achieved without noticeable plastic deformation [32].

In the field of oil and gas industries where deep water is involved, a study by Escrivà-Cerdan et al. [31] established that low-level steels are required to handle extreme temperatures and pressures and these steels should have adequate mechanical and chemical properties to withstand stress and corrosion during operation. However, a predominant corrosion issue is the dissolution of CO2 in water containing hydrogen fluids on the internal parts of the steel. Thus, heat treatment plays a major role in developing steel that CO2 corrosion resistant inclined. Additionally, the result of the tempering heat treatment on chromium-molybdenum low alloy revealed soft steel which could be attributed to a reduction in the dislocation density and uniform corrosion as well. This is considered at high tempering temperatures and times [27].

While tempering heat treatment is suitable in the modification of low alloy steel and in improving its corrosion resistance, several controversies have been raised regarding the corrosion behavior of low alloy steel. For instance, Zhang et al. [32] conducted different tempering heat treatments in a wet environment by using different tempering temperatures to investigate and compare the variation in the corrosion resistance. The results indicated that there was tempering temperature influenced the initial corrosion due to the grain distribution. Thus, slight corrosion was observed on the specimens tempered at low temperatures due to reduced internal energy. However, with the decrease in temperature of tempering, improvement was observed in the corrosion resistance.

There is increasing demand for high-strength structural steel for building a sustainable bridge. However, a major limiting factor is that these high-strength steels are subjected to corrosion in a degradation environment due to the corrosion and fatigue loading that will result in eventual failure [26]. Also, there is a need to investigate Q690qE high-strength steel as it is also prone to corrosion fatigue failure in marine environments. Thus, there is an urgent need to investigate the fatigue characteristics of high-strength bridges in a degradation environment and improvement the corrosion property to reduce fatigue damage.

To this end, Wang et al. [34] investigated the mechanical and corrosion fatigue behavior of the Q690 high-strength steel by comparing them using a thermo mechanically controlled process and tempering process. The result there was the unique corrosion fatigue behavior of the sample treated using the thermal mechanically controlled processing and tempering compared to the one produced via quenching and tempering [34]. More so, the steel developed using thermal mechanically controlled and tempering processes was observed to be associated with low ductility and corrosion fatigue. Additionally, some microcracks were occasioned by the increase in the intensity of dislocation. On the contrary, the steel produced using the inter critical quenching and tempering process was reported to be characterized by adequate mechanical and corrosion fatigue properties. Variations in the tempering temperatures (T3 and T8) of Al-Cu-Li (2198) alloy revealed different corrosion resistance behavior. The electrochemical impedance spectroscopy analyses showed that pitting corrosion ensued between the range of 1-6 hours, beyond this time, corrosion was severe after 12 hours. While the T8 tempering showed reduced corrosion resistance in the oxide films during the first exposure, the corrosion damage occurred gradually as compared with the T3 [32].

2.7 Carburization

For carburization, the metal is heat-treated using a medium that releases carbon as deposits on the metal. The carbon is absorbed into the surface of the material and increases the carbon content which eventually increases the hardness which becomes harder than the core. It is a rational heat treatment method that consists of integrates quenching with carburization [33]. It is categorized into quenching, carburization condition, and equipment for carburization. Successful steel decarburization depends on the earlier-mentioned method of carburization, despite many factors which can hamper the successful carburization performance, an adequate combination of the carburization conditions will provide hardened steel with added mechanical properties [34].

In terms of Carburisation kinetics, molybdenum is best achieved at elevated temperatures in the presence of the carburizing media which is graphite. However, the actual reaction occurs at 1200oC where different layers of Mo2C are formed on the surface of the metal. This occurs via the diffusion process and the surface is found to be thickened in the form of parabolic kinetics [30]. In the case of tungsten, the behavior is similar, but carbides grow faster in molybdenum during carburization. More so, the carbide layers slow down whole-scale carburization and cause embrittlement of the material. A major problem with molybdenum in a halogenated environment is that it has poor corrosion resistance compared with tungsten [35]. The low carburization technique has gained wide application in improving the mechanical and tribological properties of austenitic steel. This is carried at a temperature below 500 oC to prevent the formation of chromium carbide in the carburized region. During the process of carburization, carbon atoms are noted to incorporate into the face-centered cubic austenite structure without the formation of chromium carbides, thus, a hardened layer of 40 µm thick with about 3 wt% carbon obtained [36].

3 Conclusion

The study explored the various heat treatment methods and their varying effects on the corrosion performance of metals and their alloys. The review established that there are majorly three steps in the heat treatment process with respective methods used. These processes include heating, which is usually carried out to modify the structure of the materials/alloys after a certain temperature. In this case, the alloy can be said to be at room temperature by solid solution, mechanical mixture, or combination of the two [37].

In the case of the solid solution, two metals are mixed without their chemical combination to form a solid solution. In the case of mechanical mixtures, elements and compounds are combined and, in most cases, compacted. The next important process is known to be soaking and this is the stage where the metal has completely change in structure due to the effect of heating. It normally appears reddish at this stage and this equally depends on the mass of the metal and the heating rate. The next stage of the heat treatment process after soaking is the cooling stage and this involves different media, which could be air or oil [38]. At this stage, the structure is equally transformed from one chemical composition to the other. However, it depends on the cooling method employed during the process. All three processes are important during the heating process. These stages will help in understanding the various microstructural evolutions and subsequent mechanical properties as well as the corrosion performance of the heat-treated metal and alloys [39]. While different properties evolve during heat treatment processes, it is important to know that various applications and metal compositions are factors to be considered in the selection of the appropriate heat treatment method

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