

Influence of Varying Grain Size & Microstructural Constituents on the Corrosion Rate of Steel- An Overview

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Abstract: Variation in grain sizes via different approaches affects steel's microstructural properties and corrosion performance. Hence, there is a tendency for internal stress, strain, and texture in the alloyed material. This study established that grain refinement does not necessarily change the corrosion rate, especially for coarse grain size. However, it increases when the refined grain size is deployed into the material. However, the reason for the variation in the corrosion performance behavior of the two types of grains lies in the type of experimental set-up and its application. Subsequently, it was established in this study that the mechanical and microstructural performance of steel depends heavily on the type of grain boundaries. Thus, refined grain boundaries help as surface asperities in materials which eventually improves the microstructure and, most importantly, its corrosion performance in a particular medium.

1. Introduction

There are several methods of determining grain sizes of particles or materials. Some determined based on etched metallographic sections after being grounded and polished using different sizes of abrasives/emery clothe. Variations in grain sizes are usually allowed for some materials from 2.8 to 500 μm . In the case of some materials which have homogenous properties, the surface may be characterized with small sizes of grains and not large. Thus, grain sizes are a function of area of application of the material. However, to achieve excellent mechanical properties, like strength, the smallest object dimension must be ten times larger than the grain size [1].

According to a study by Karihaloo and Knauss [2], grain size has great effect on the fracture toughness of ceramic material made of ferroelectric. Observation of grain sizes of PLZT9/65/35 ceramic material via optical microscope revealed that there was reduction of size of crack as the grain size reduces while the diagonal pyramid remains the same with the grain size during hardness test.

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Also, reported in the study was the use of multdomain grain model technique to explain the behavior of the ceramic grain size. It was suggested that there was presence of multidomain state in the ferroelectric ceramics which is characterized by large grain size but exhibited a single domain state due to the reduction in grain size [3].

Thus, the presence of small grain size will cause the stoppage of the residual stress by the single domain state, hence this unreleased residual stress will help in increasing the fracture toughness of the material [4]. Similarly, it was established that reduction in grain size polycrystalline ferroelectric material caused a corresponding increase domain of wall spinning, hence losses are equally reduced. Thus, the decrease in grain sizes will as well cause the phase transition of the grain crystal to diffuse easily [5].

According to Kim *et al.* [6], grain size variation on tensile behavior of austenitic steel revealed an increased elongation loss which showed a relative behavior after the hydrogen charging. Also, there was loss in ductility which was attributed to the smoothness of the grain alloy and rate of propagation in the cracks as well as drop in the strain hardening rate of the alloy because of the hydrogen charging. However, Schmid factor analysis revealed the improvement in the dislocation process of the grain alloy. However, when compared with the coarse grain alloy, it was observed that there was transfer of hydrogen to the boundaries of grain as well as enormous gathering behind the boundaries and resulted into a more severe hydrogen embrittlement. Interestingly, the stress concentration at the grain boundaries as well as the crack propagation were reported to be the cause of premature failure in alloys produced from fine grain [7].

It was established that sizes of grain remains critical factor of some nanostructured materials like steel, however, its inadequate characterization has led to its utilization and performance in most applications. Several methods exist for the processing of grain size distribution and at moderate or high temperature, several grain sizes could be obtained [8]. Transmission electron microscope measurement of grain size showed varying distribution of grain size ranging from 20 to 500 nm while the majority of the grains fall between 50 and 80 nm. Strain hardening is a depend on grain sizes and also, it is a major factor in the modelling of mechanical properties of materials [9].

According to Crouch *et al.* [10], the importance of grain size variation cannot be overemphasized especially, according to Hall-Petch equation which states that yield strength is inversely proportional to the square root of grain size. Thus, small grain size is always required for hardenability and plastic flow behavior of materials. More so, in the case of wrought steels, because of its processing behavior texture is generated within the grains and cause crystallographic arrangement [11]. Thus, size of grain give rise to variation in mechanical properties which represent the essential properties of the material. In most cases, there is always inadequate fracture toughness due to the shape and sizes of grains. That is why armour steel is mostly deployed in specific applications because of small and equiaxed grain presence in the steel.

Moiduddin *et al.* [11] established that friction stir welding is widely used in the aerospace and automotive components' fabrication especially in the welding extruded plate which has a thickness of above 10 mm. however, thermal variation exists in the shoulder region of the plate and this result to microstructural variation in the welded region as well as reduction in the performance of the welded joint. Thus, the grain size variation reflects in the welded structure [12]. Thus, the study examined the effect of using friction welding on an aluminium AA2519 alloy to examine the variation in the grain size in the welded region. Figure 1 revealed the variation in the different regions of weld as obtained from the scanning electron microscope. From the image, it was observed that different regions numbered 1 to 8 revealed

the varying microstructures. Also, Figure 2 equally revealed the average sizes of the welded region [13].

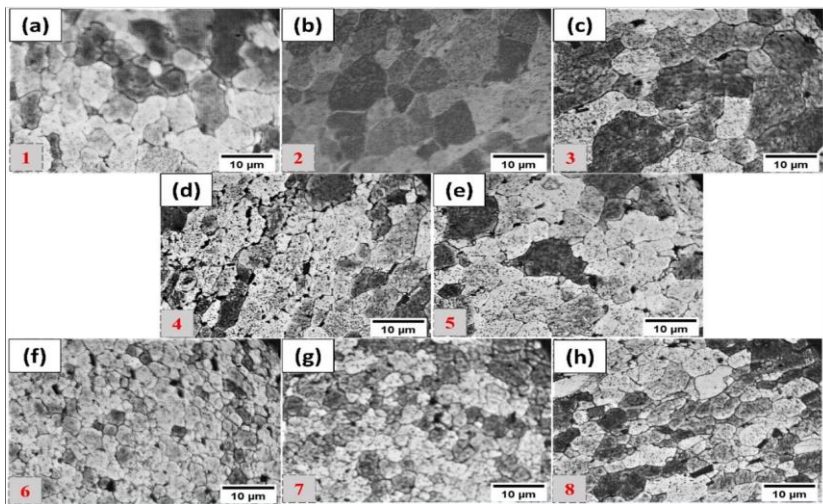


Figure 1: microstructures of 8 locations Source: [11]

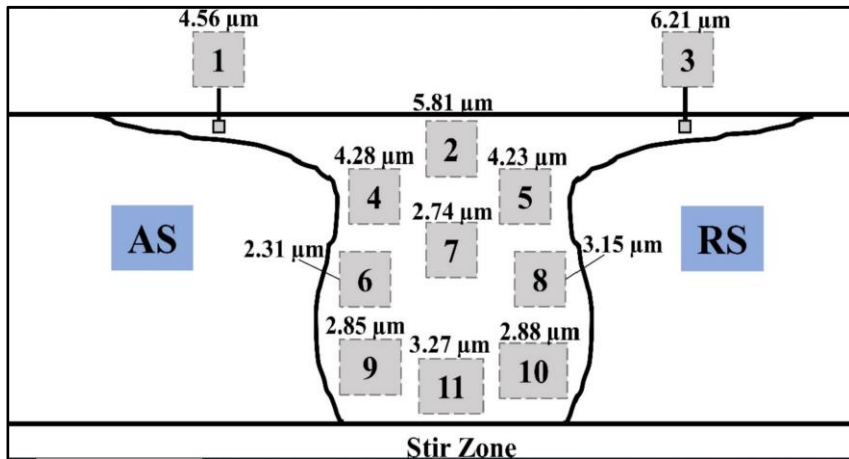


Figure 2: Grain size analyses of friction welded regions Source: [11]

Mariappan *et al.* [14] conducted a low cycle fatigue tests on a weld steel and examined the coarse grain heat affected zone, fine grain heat affected zone and intercritical heat affected zone using varying amplitudes it was observed that that the P91 weld metal exhibited a softening behavior and it became consistent. Also, in the heat affected zone and the fine grain heat affected zone exhibited excellent fatigue behavior. However, in the region of coarse grain and intercritical coarse grain heat affected zones, there was increased fatigue lives within the lower and higher strain amplitudes. Thus, there was an establishment of a model for predicting the fatigue life of the welded metal [15].

Gsellmann *et al.* [16] established that adhesion of coatings to the substrate is a critical factor that usually influence the cutting tools. Thus, to determine the adhesion of TiN hard coating and the microstructural constituents of high-speed steel, a transmission electron microscope and a modelling approach was used. The experimental result revealed that the coating (TiN) have excellent adhesion to the carbides while there was reduced adhesion on the martensite matrix. Thus, the new method for steel development that will increase the coating (grain) adhesion is important [17].

Similarly, the adhesion of the protective coating is also important for the understanding of the mode of failures especially in metal working process. The majority of techniques used in the determination of the coating adhesion include scratch and indentation for various samples. However, quantitative measures used to determine strength of the interface of the microstructural constituents are still lacking. Especially for samples involving composite coatings. To resolve this, Gsellmann *et al.* [18] investigated the interfacial strength and the adhesion of hard coating of TiN deposit on MC-type carbide and M6C-type carbide as well as on martensite which was deployed as constituent of high-speed steel. Scanning electron microscope and micromechanical tester were used for the characterizations. The result showed that the stress at the interface caused fracture as analysed using finite element analysis. Thus, there was increase in the strength at the interface and coating adhesion occur from higher level to a lower strength level [19]. Dong and Shen, [20] also conducted an experiment to improve the mechanical and corrosion properties of trip steel via the adjustment of microstructural constituents. It was reported that the retained austenite stands at approximately 30 % in about 0.5 wt.%C trip steel. However, the microstructure of the retained austenite displayed film-like, mixed film like as well as blocky patterns. More so, there was high tensile strength of about 1220 Mpa and excellent ductility. Also, there was decrease in the volume fraction of bainite ranging from 53 to 44 vol. % as well as that of martensite-austenite which increase from 2 to 9 vol. % [21-22].

2. Grain Size Refinement

Refinement of grain size is a method of improving the mechanical properties of the materials via decreasing the grain size of that material. In some terms it is referred as inoculation. Babu *et al.* [23] investigated the effect of grain refinement on the compression behavior of 30H austenitic stainless steel using a temperature of 1223 K. the results from the flow curves revealed the flow stress which varies inversely proportional to the average size of the sub-grain diameter in the case of the fine and coarse grain samples tested at high strain. Furthermore, the fine grain deformed at low strain and exhibited dynamic recrystallization as well as discontinuous recrystallization process [23].

Thus, the continuous dynamic recrystallization had disorientation within the boundary while the discontinuous dynamic recrystallization was characterized by bulging and migration of strains. In contrast, it was reported that the continuous dynamic recrystallization was characterized by microbands which was equally associated with grain refinement in the fine-refinement sample at higher strain rate. More so, there was improvement in the refinement of grains kinetics with rate of strain and the initial size of grains and these findings provides a potential opportunity for adequate microstructural alloy control during hot working at varying strain rate [24]

Figure 3 showed the stress-strain curves for the coarse and fine-grained samples which deformed at a temperature of 1223 K. from Figure 3a, there was increase in the flow stress at the initial stage of the compression and this was attributed to the work hardening effect. Also, the fine-grained sample revealed important flow softening effect which reflect on the peak

stress in the strain rate [25]. However, in the case of coarse-grained sample, there was no visible softening and there was steady state at the peak of the flow stress. More so, Figure 3b showed the sensitivity of the strain rate at varying values. It was established that in the case of fine-grained sample, the value of m changed in marginal pattern from 0.16 to about 0.125 as the strain rate was increased from 0.001 S-1 [26]. In the case of the coarse-grained sample, value of m revealed a decline from 0.145 to 0.08 at the same strain rate. Similarly, Figure 4 illustrate the map of the grain boundary of the as-received state of the fine and coarse grain samples. From the Figure, it was observed that the structure was characterized by equiaxed grains in the fine and coarse grain of the as-received. Both the as-received showed a recrystallized structure. More so, Figure 4c presents disorientation in the distribution of the grains [27].

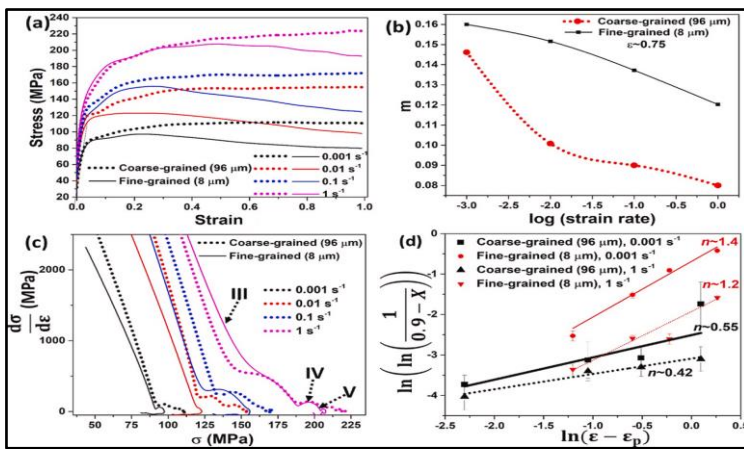


Figure 3: Flow curves of samples Source: [23]

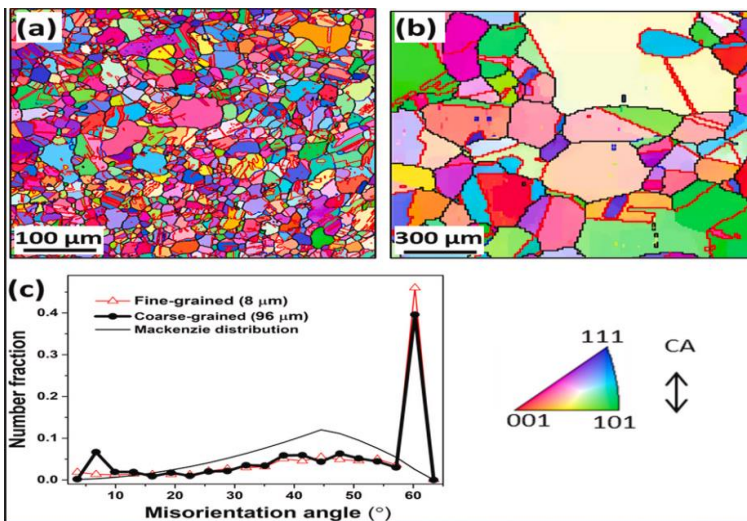


Figure 4: Grain boundaries of As-received samples Source: [23]

In the study by Ding *et al.* [28], it was established that the traditional thermo-mechanical control processing has been widely deployed in the refinement of the hot rolled steel. Despite this, the method is not considered the best due to their limitation in the reduction ratio of large steel structure. Thus, the study employed a method known as boundary induced transformation for grain refinement of steel structures which are very large. Titanium alloy was used to control the grain size at the austenite during the reheating and rough rolling operations. The result showed that ferrite grain size was reduced significantly using the boundary induced transformation and the refined grain size was useful for the large steel structure as well as its reduction ratio [29].

According to Wang *et al.* [30], it was reported that extended duration in homogenization treatment of wrought aluminium alloy is quite important. However, the energy consumption is high. Thus, the study investigated varying homogenization time Al-Mg-Si-Cu alloy after hot extrusion process, solution as well as aging process. The result showed that the unhomogenized alloy exhibited excellent strength which can be attributed to the presence of fine micron of α -AlFeMnSi particles during homogenization [31]. These particles (dispersoids) tend to occupy the silicon content that was used in the formation of MgSi-rich nanoprecipitates causing reduction in the volume fraction of the precipitates. However, there was reduction in nucleation region for the case of dynamic recrystallization and the sticking effect of the grain boundaries due to the α -AlFeMnSi transformations. Hence, there was presence of fine and high-density precipitates of the alloy without homogenization treatments. These findings provide important insights into processing as well as conservation of energy during during the production of high performance alloys [32].

Thulasiram *et al.* [33] investigated the performance of Inconel 718 of refined grains in terms of texture at bvarying elevated temperature of between 500 oC to 800 oC. The grain distribution patterns were investigated using electron back scattered diffraction, also, scanning electron microscope was used to observe the various microstructural changes that evolve heat treatment. The results revealed that the Inconel 718 that under heat treatment at 800 oC exhibited excellent refined grains and optimized texture. Also, decrease in grain size led reduction in cleavages that caused a corresponding increase in ductility. Figure 5 showed the electron back scattered diffractions for all the samples heat treated at varying temperatures of 500 oC to 800 oC. it was reported that samples were first quenched in water to prevent recrystallization. From the microstructure, it was observed that at 800 oC, there was excellent phase transformation and the obtained grain size was about 9.5 micron. Also, from the micrograph, some regions of grain boundaries were occupied by precipitates and they appeared wet completely while the rest experienced incomplete wetness [34].

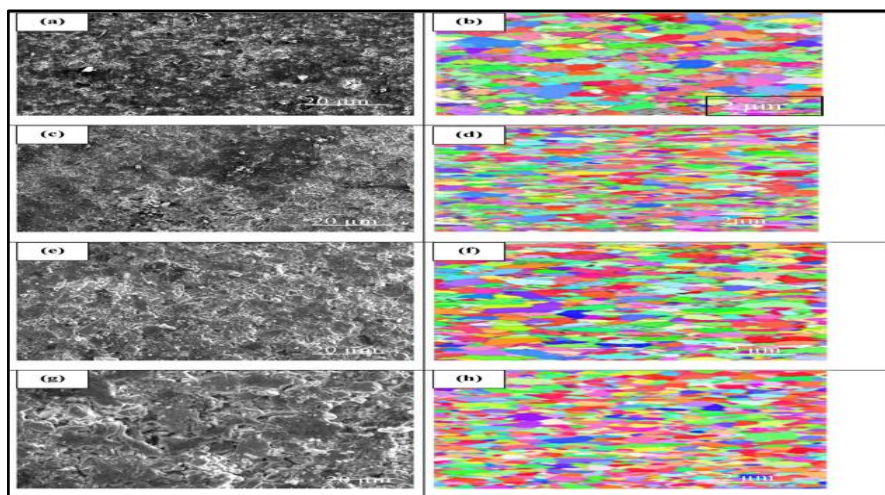


Figure 5: SEM microstructure (a,c,e,g) and EBSD (b,d,f,h) of regions heat treated from 500 °C, 600 °C, 700 °C and 800 °C Source: [33]

3. Effect of Grain Size variation on Corrosion rate of Steel

Variation in grain sizes of constituents have several implications on the electrochemical properties of steel and its alloys. For instance, Peral *et al.* [35] revealed the impact of tempering and grain refinement on the corrosion performance a low alloy steel using electrochemical analysis technique. The result involving linear polarization, potentiodynamic and electrochemical impedance spectroscopy revealed there was improvement in the corrosion resistance at a temperature of between 200 to 500 degree centigrade. Furthermore, application of intense shot peening treatment to the sample with excellent corrosion performance to optimize the grain structure showed reduction in corrosion resistance after the shot peening treatment [36].

According to Prakash *et al.* [37], application of refined nano-scale grain on the corrosion resistance performance of 301L austenite stainless steel having martensite and about 87 % cold deformation revealed that there was decrease in corrosion rate of for the material. Especially when it attained the bimodal and unimodal shape. The electrochemical impedance spectroscopy result revealed thick as well as less defective passive film for the case of unimodal shape of the grain. Also, the microstructural images revealed martensite which was induced during the rolling as well as austenite nan-grains structure during the annealing process [38].

Yang *et al.* [39] investigated the effect of microstructural evolutions on pitting behavior of 304 stainless steel via electrochemical measurement. The results revealed coarsening of grain caused a reduction in the corrosion resistance rate of the material in the coal chemical salt water medium. Also, there was promotion of passivation as a result of large and high angle grain boundaries and this also result into defect formation on the passive film. Furthermore, it was reported that pitting increased due to the grain coarsening. Also, the depth of the pits increased gradually resulting in the overall change in the stability of the pits [40]. Zhang *et al.* [41] also investigated the microstructural evolution and corrosion behavior of 304 stainless steel strengthened with oxide and it was compared with a forged 304 stainless steel. It was reported that the microstructure of the steel was dominated by austenite grains of 56 microns. Also, the corrosion density of the strengthened steel was observed to

be $1.13 \mu\text{A}/\text{cm}^2$. However, it was also observed that the grain size of the strengthened steel was found to be finer which assisted the corrosion resistance. Hence, the corrosion resistance of the strengthened steel was found to be better compared to the 304 stainless steel. Figure 6-7 showed the image and the corrosion behavior of both the 304 austenitic steel and the treated steel [42].

Consequently, the microstructural evolution of low carbon steel is greatly a function of the structure of the size of the ferrite grains. Finer grain sizes are more favourable in terms of the mechanical properties [43]. However, because of increased energy as well as chemical action of the grain boundaries, there is tendency of the reactivity of the surface due to increase in the electron activity as well as surface diffusion. Thus, the corrosion of such material would definitely be affected. Thus, studying the impact of variation in grain size is very critical to material expert and engineers [44].

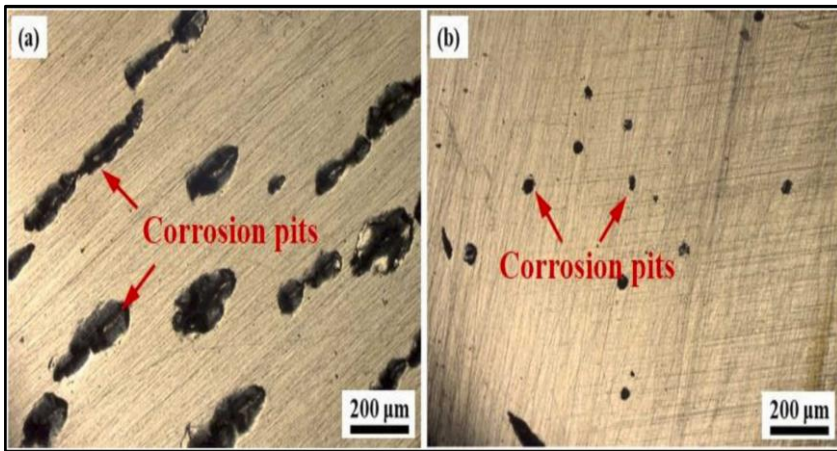


Figure 6: Optical image of the 304 stainless steel (a) strengthened stainless steel Source: [41]

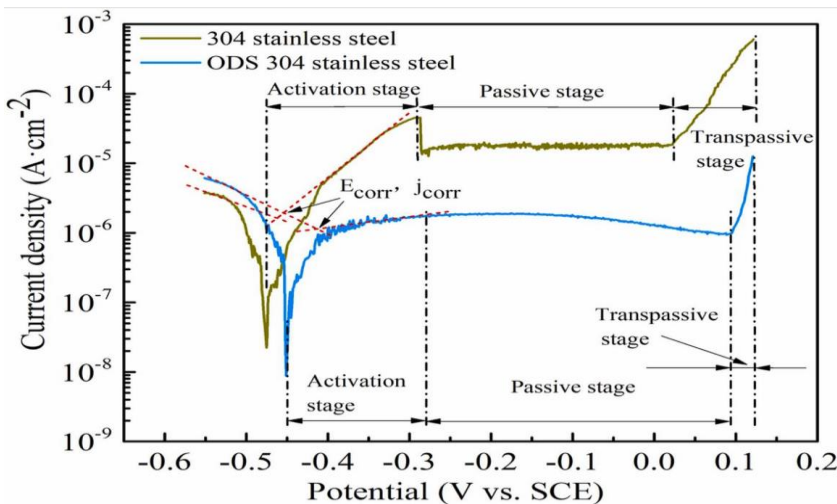


Figure 7: Potentiodynamic behavior of 304 stainless steel and strengthened stainless steel Source: [41]

4. Conclusion

Grain size variation on corrosion resistance and microstructures of steel have been carried out to understand its effect. It was established in the study that the active behavior of coarse grain substrate in a medium will automatically improve if the coarse grain is changed to a refined grain. Thus, surface activity of material in electrochemical process is a function of the grain sizes. However, the ability of the substrate to exhibit a passive behavior helps the material to exhibit stability in the protective film. Furthermore, the grain boundary energies are higher individually than when they are in bulk. Thus, there is possibility increasing the diffusion rate as a result of grain refinement.

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