Scientific Research Publishing

Image J Analysis of Six Different Annealed Temperatures of 0.17% C of HSLA Steels

Ngozi Grace Emordi[1], Iweriolor Sunday[2], Onyekpe Basil Obimma[3]

[1]Department of Metallurgical Engineering, Delta State Polytechnic, Ogwashi Uku, Nigeria
[2]Department of Mechanical Engineering, Delta State Polytechnic, Ogwashi Uku, Nigeria
[3]Department of Mechanical Engineering, University of Benin, Benin, Nigeria
Email: sundaytrevor1234@gmail.com

Abstract

Annealing is a heat treatment procedure in which the mechanical properties of a material are being altered, and such alterations cause changes in its properties such as strength and hardness. It is usually carried out to improve ductility and toughness, to reduce hardness and to remove carbides. This study deals with the use of image analysis processing method for the measurement of structure of six annealed samples of 0.17% High Strength Low Alloy (HSLA) Steels (840°C - 990°C) with 30°C interval and 30 minutes soaking time. From the optical microscope images using Image J program, some parameters like calculation of area, pixel value statistics, distances and angles measurements, edge detection, such as the circularity, ferret angle, solidity and perimeter, average area and the percentage area were examined. The annealed sample of 960°C gave the highest grain count of 543 with a perimeter of 41.518; standard deviation 7.057 and a mean of 28.722 which shows that annealing greatly improved the fatigue life of the steel. From the mechanical analysis result, the annealed sample at 840°C has a highest hardness value of 129.4 BHN and gave the lowest impact value of 58.75 J. This study shows a significant decrease in the hardness value as the annealing temperature increased which signifies that annealing temperature enhanced the fatigue property and tensile strength (wear strength) of the steel in study.

Keywords

High Strength Low Alloy Steel, Microstructure, Image J

1. Introduction

An important feature of any Engineering component is its fatigue life and it's measured by the number of cycles it can withstand before Fatigue failure takes

place. Fatigue is a problem that can affect any type of component that moves [1]. Heat treatment is an operation or combination of operations which involve heating at a specific rate. The aim is to obtain a desired microstructure to achieve certain predetermined properties (mechanical, physical, electrical or magnetic). Heat treatment and alloying are two methods which are considerably used for controlling material properties. In heat treatment, the microstructures of the materials are altered, which influences mechanical properties such as strength, ductility, toughness, hardness and wear [1]. Annealing in metallurgy and materials science is a heat treatment that alters the physical and sometimes the chemical properties of a material to increase its ductility and reduce its hardness, making it more workable. It involves heating the material to above its recrystallization temperature, maintaining a suitable temperature, and then cooling. [2] and [3] described annealing process as a thermal system applied to a material to transform or modify its internal structure from cold worked propagation; metallurgically, the effect of these changes in properties impacts on the performance characteristics and the expected application [4]. Annealing is the type of heat treatment most frequently applied in order to soften iron or steel materials and refines its grain due to ferrite-pearlite microstructure; it is used where elongations and appreciable level of tensile strength are required in engineering materials. [5] described annealing as a heat treatment procedure in which a material composition is altered, and such alterations cause changes in its properties such as strength and hardness. In this process, a material is heated to an elevated temperature for a specific period of time and then slowly cooled in the furnace. This kind of process is usually carried out to relieve stresses and improve ductility. It often enables the design of desired microstructure by altering the annealing parameters, such as annealing temperature and soaking time.

New materials that impart excellent structural performance; while reducing weight and being cost-effectively manufactured is on the increasing demand [6]. Due to this fact, for the past 30 years now, an exceptional type of steel which has low amount of carbon (0.05 - 0.25) and also combines with other alloying elements like Cr, Ni, Mo, Cu, N, V, Nb, Ti, W, and Zr, in little proportions and in diverse concentrations has evolved often known as high strength low alloy HSLA steels. Manricino, in his work on fatigue failure analysis of High Strength Low Alloy steel sheet described High strength low alloy steels (HSLA) as steels that are made up of microstructures formed by hard martensite particles distributed in the ductile ferrite matrix [7]. They are compared to dual-phase steels due to their high hardening ability during deformation, high malleability and good surface quality [8]. It also contributes to the stiffness and weight reduction being preferred in automobile industry. This is attributed to its good formability characteristics. These groups of steels play an effective role in the production of parts in vehicles such as suspension systems, support elements, longitudinal beams, transverse components and chassis [9]. When these materials are exposed to high temperatures, there is a recrystallization of the microstructure in

the heat affected zone which directly influences the resistance limit of the material [10] Utilization of HSLA steels are found in many engineering fields which include oil and gas pipelines, constructions and farm machinery, heavy-duty highway and off road vehicles, industrial equipment storage tanks, mine and rail road car, barges and dredges snow mobiles, power transmission towers light poles, lawn mowers, and passengers car components. Bridges, offshore structures, and building beams and panels are additional uses of these steels [11].

Image analysis deals generally with acquisition of quantitative information about various parameters of microstructure of a material such as determination of percentage fraction of phases, particular size, circularity etc. Circularity can be calculated as a shape parameter index in the Image J software. The definition of circularity (C I) in the Image J software is as follows:

$$C_1 = 4\pi \frac{A^1}{P_1^2} \tag{1}$$

where, A^1 and P_1 are the area and the perimeter using Image J.

There are numerous commercial software such as Amira, Comsol multiphysics, etc., for analysis features [12]. However, this paper describes an investigation of six different annealed samples from 840˚C - 990˚C with 30 ˚C interval of 0.17% C HSLA steels structure analyzing from OM image using Image J program software [13]. Several researchers have investigated DP steels to find out the effect of heat treatment, soaking times on its properties. Miroslaw, 2020 observed that annealing process reduces the true stress and effectively decreases the hardness of 42 $CrMO_4$ Steel and also improves microstructural Spherodization [14]. Senthil reported that improved fatigue strength was attainable by the combined heat treatment process of Nitriding followed by induction hardening [15]. The quantitative measurement of the influence of Annealing on the fatigue life of SAE202 and 440˚C steels from his results, he concluded that there is a definite improvement in the fatigue life due to annealing in both steels; however, the extent of improvement was more in 440˚C steel when compared to SAE202. Gaurav, 2018 reported that to improve fatigue life, effect of heat treatment on fatigue life and strength need to be studied for better designing and mechanical system. Also, little or no work has been done to set out the fatigue life of HSLA steel at different annealing temperature; hence this work investigated on the use of Image J to analyze the effect of annealing temperatures on the fatigue properties of 0.17% C HSLA steels.

2. Materials and Method

Samples of HSLA steel containing about 0.17% Carbon were provided and used for this experiment. The samples were grouped into 10 having 5 samples in each of the group. They were then heat treated at different pre-determined temperature as follows: 840˚C, 870˚C, 900˚C, 930˚C, 960˚C and 990˚C respectively and the control which served as the austenizing temperature. Furthermore each of these group of five were held at 30 minutes interval and were then left to cool in

the furnace (annealing) before various test were carried out on them..

2.1. Heat Treatment

This section is aimed at producing microstructures from the as-received steel through different annealing temperatures. The focus here is to develop different microstructure at different temperatures for each of the samples, with a view to determining the effect of the new microstructures on the mechanical properties of the investigated steel.

2.2. Normalizing

This was done to remove the effect of past mechanical, thermo-mechanical or thermal treatment the steel has been subjected to. This was done by heating the sample to 890°C, soaking for one hour (1 hr) in the furnace (muffle) and then allowing it to cool in air.

2.3. Annealing

Before the annealing was done the Carbon equivalent was calculated to tell the starting temperature from the Iron Carbon phase diagram.

$$CE = C + \frac{Cr + Mo + V}{5} + \frac{Mn + Si}{6} + \frac{Ni + Cu}{15} \qquad (2)$$

From the chemical composition, we have

Cr = 0.2559; Mo = 0.0100; V = 0.0100; Mn = 1.2089; Si = 0.3016 Ni = 0.1218 and Cu = 0.2560 and C = 0.17

Substituting these figures in Equation 2 above, we have

$$CE = 0.17 + \frac{0.2559 + 0.0100 + 0.0100}{5} + \frac{1.2089 + 0.3016}{6} + \frac{0.1218 + 0.2560}{15} \qquad (3)$$

$$CE = 0.17 + 0.05518 + 0.25175 + 0.02513 = 0.50206 \quad \text{hence} \quad CE \text{ is } 0.5 \qquad (4)$$

2.4. Metallographic Examination

2.4.1. Grinding

This operation aims at producing a perfectly flat and smooth surface Silicon carbide papers of different grades placed on the grinding machine was used in the order of 220, 320, 400 and 600 grits paper *i.e.* from coarse grade to finer grade. The grinding process was done under running water to wash away the grits and also to avoid overheating. The samples were turned through 90° while changing from one grit size to another in the materials laboratory at Obafemi Awolowo University, Ile-Ife. Osun state, Nigeria.

2.4.2. Polishing

A universal polishing machine was employed. A polishing cloth (selvt cloth) was placed on the polisher for the initial polishing swamped with solution of one micron of silicon carbide solution, then, followed by the final polishing stage with salvet cloth swamped with solution of 0.5 μm Silicon carbide until a mirror-like surface is attainable. It is then washed and dried.

2.4.3. Etching

This is done to reveal the microstructure of the polished surface. Etching is the selective attack on the grain boundaries being a region of high energy and dislocation density. The mirror-like surface was etched in 2% NITAL. The sample was again washed, dried and later viewed under the metallurgical microscope.

2.4.4. Optical Microscopy

The samples were etched in 2% NITAL (2% Nitric Acid and 98% Ethyl Alcohol), they were put in a desiccator and viewed with metallurgical optical microscope.

3. Results and Discussion

Figure 1 showed the flowchart of the Image J process of HSLA Steel. In Figure 2(a) Steels taken with metallurgical Optical microscope. The images were uploaded and analyzed with image J software after the capturing of the micrographs. The Image J analysis was then used to analyze for the following parameters, standard deviation, perimeter, angle, circularity, percentage area, ferret angle, roundness, solidity, histogram, 3D dimensioned and results are presented in plate 1:0. Images in Figure 2(a) were threshold by using Image-Adjust and Threshold tool. The threshold color images of Figure 2(b) were masked to give the outlines in Figure 2(d) while Figure 2(f) showed the 3D interactive surface plot drawn by intensity of any color offers a basic vision of observed surface morphology of the steel such as the grid size, the smoothing and the perspective of the minimum and maximum percentage in relation to the z-scale. The circularity (shape descriptors) parameter allows for evaluating the shape of grains. Figure 2(e) showed the bins which is the number used for the particle size distribution histogram while Table 1 showed the microstructural parameters of the six annealed samples of HSLA steels using the Image J analysis (Figures 2-7).
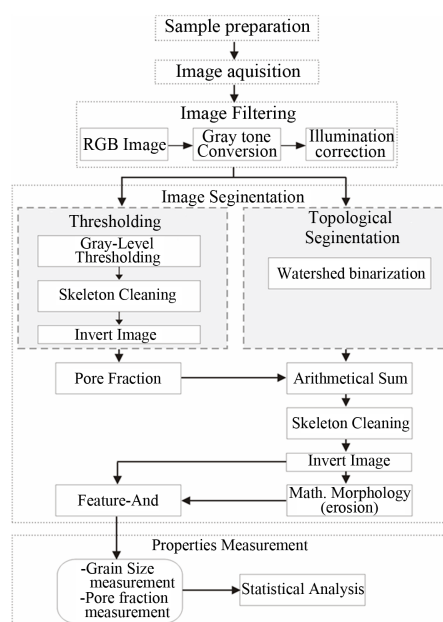

Figure 1. Flowchart of the image J process of 0.17% Of HSLA steel.
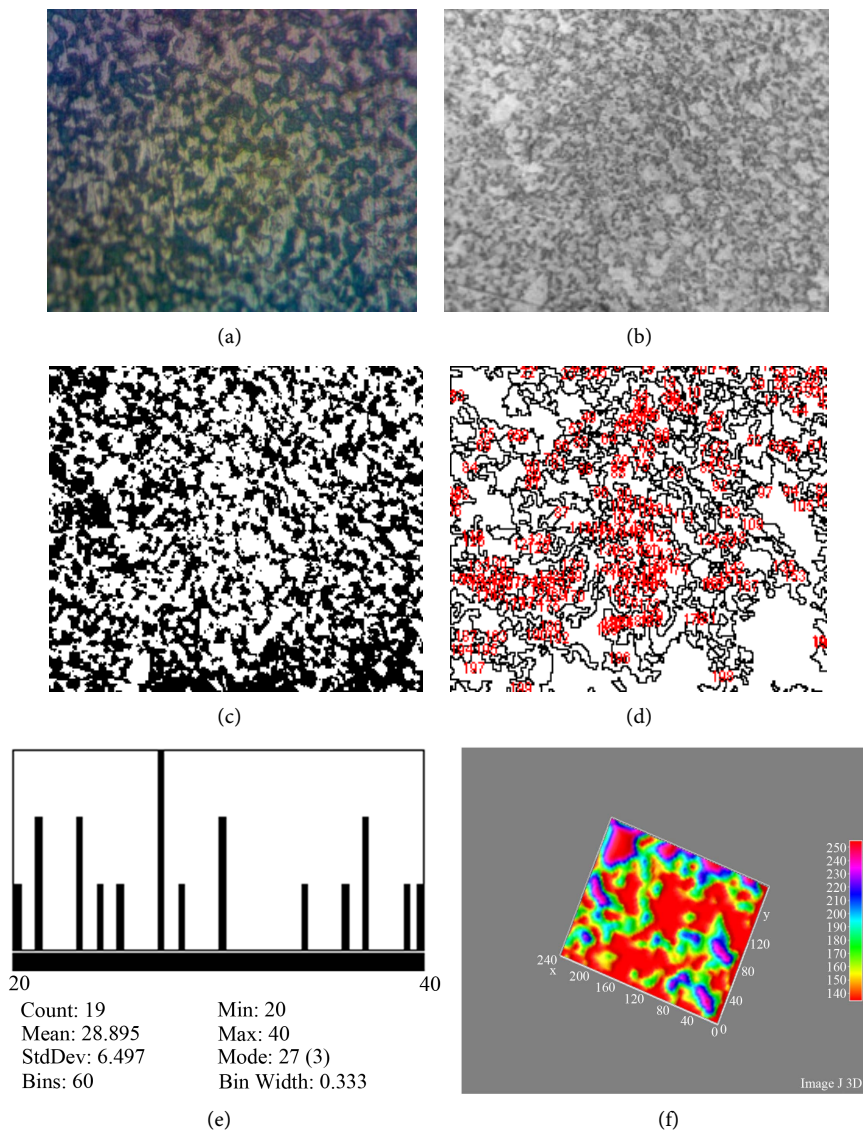
Figure 2. Processed image of 840˚C annealed steel by image analysis (using) Image J. (a) Original image - Optical Microscope (b) processing and threshold (blue); (c) thresholded (black and white) (d) result of particle distribution (using analysis tool in Image J) (e) Area distribution of the grains (f) Interactive 3D surface plot.

Table 1. Microstructural properties of six annealed samples of 0.17% HSLA steels by image J analysis.

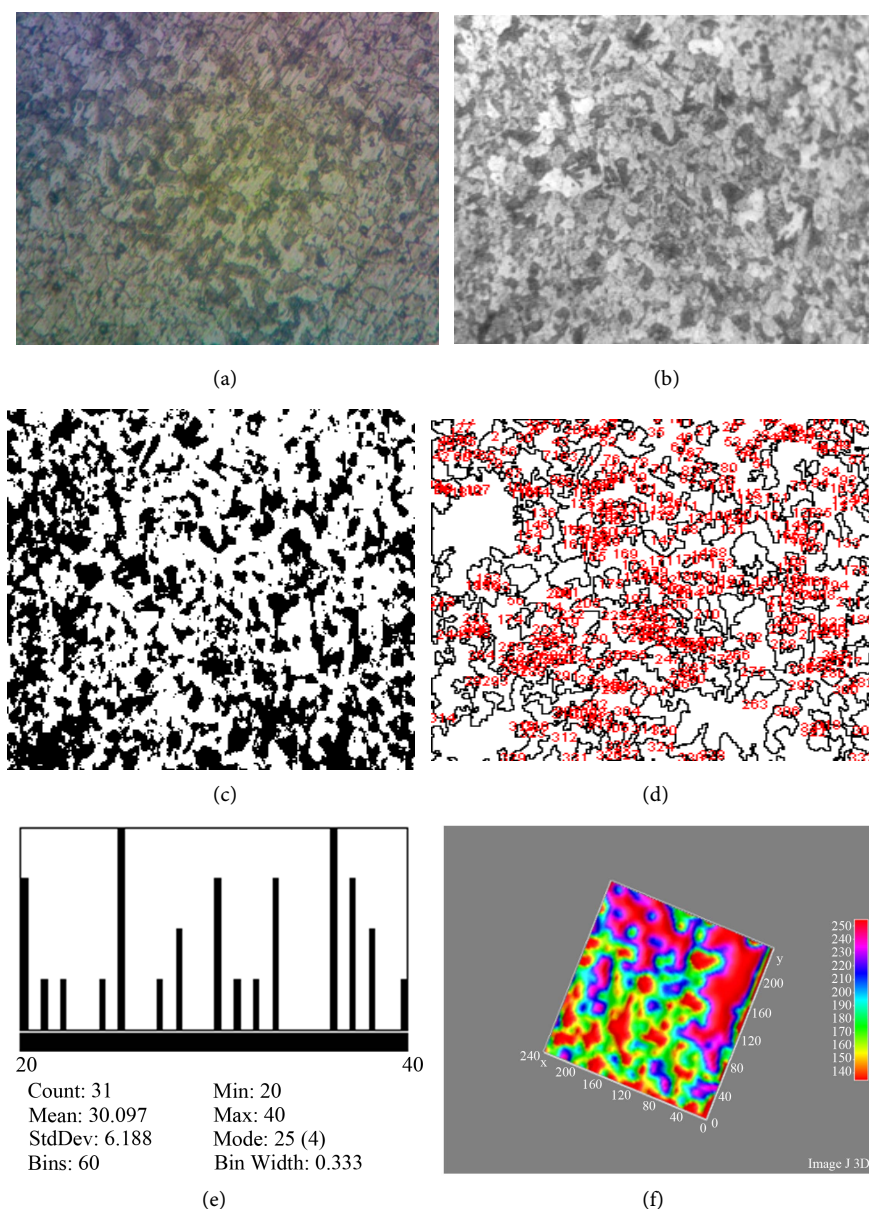| TEMP ˚C	COUNT	TOTAL AREA	AV. SIZE	% AREA	CIRC	perimeter	FERET	FERET X	FERET Y	FERET ANG	MINI FERET
840	199	22384	112.482	47.63	0.176	59.041	9.823	113.236	811.724	119.645	5.983
870	332	26309	79.244	41.45	0.359	36.901	9.801	127.145	105.611	108.258	5.248
900	182	29195	160.412	49.45	0.419	50.976	10.154	135.709	86.714	116.23	6.148
930	383	19038	49.708	41.49	0.149	30.169	7.439	131.164	78.324	111.266	4.108
960	543	51205	94.300	46.88	0.334	41.518	7.793	203.157	114.245	108.275	4.576
990	290	29802	102.766	50.68	0.224	42.166	7.534	164.414	91.910	111.731	4.305

Figure 3. Processed image of 870°C annealed steel by image analysis (using) Image J. (a) Original image - Optical Microscope; (b) processing and threshold (blue); (c) thresholded (black and white); (d) result of particle distribution (using analysis tool in Image J); (e) Area distribution of the grains; (f) Interactive 3D surface plot.

In Figure 8, the Impact and Hardness were conducted using the ASTM E23 for notched bar impact testing, from the figure, it will be observed that the highest hardness point in the series was at 129.4 BHN at 840°C the hardness decreased gradually to point 118.6 BHN which is at 990°C. It is worthy of note that 840°C also had the lowest impact value at 58.75 J and this value was seen to increase significantly to 66.65 J at 990°. However, it was observed that as the annealing temperature increased, the hardness decreased while the impact increased. This may be due to annealing; because annealing helps to relieve internal stress and improve ductility [16].
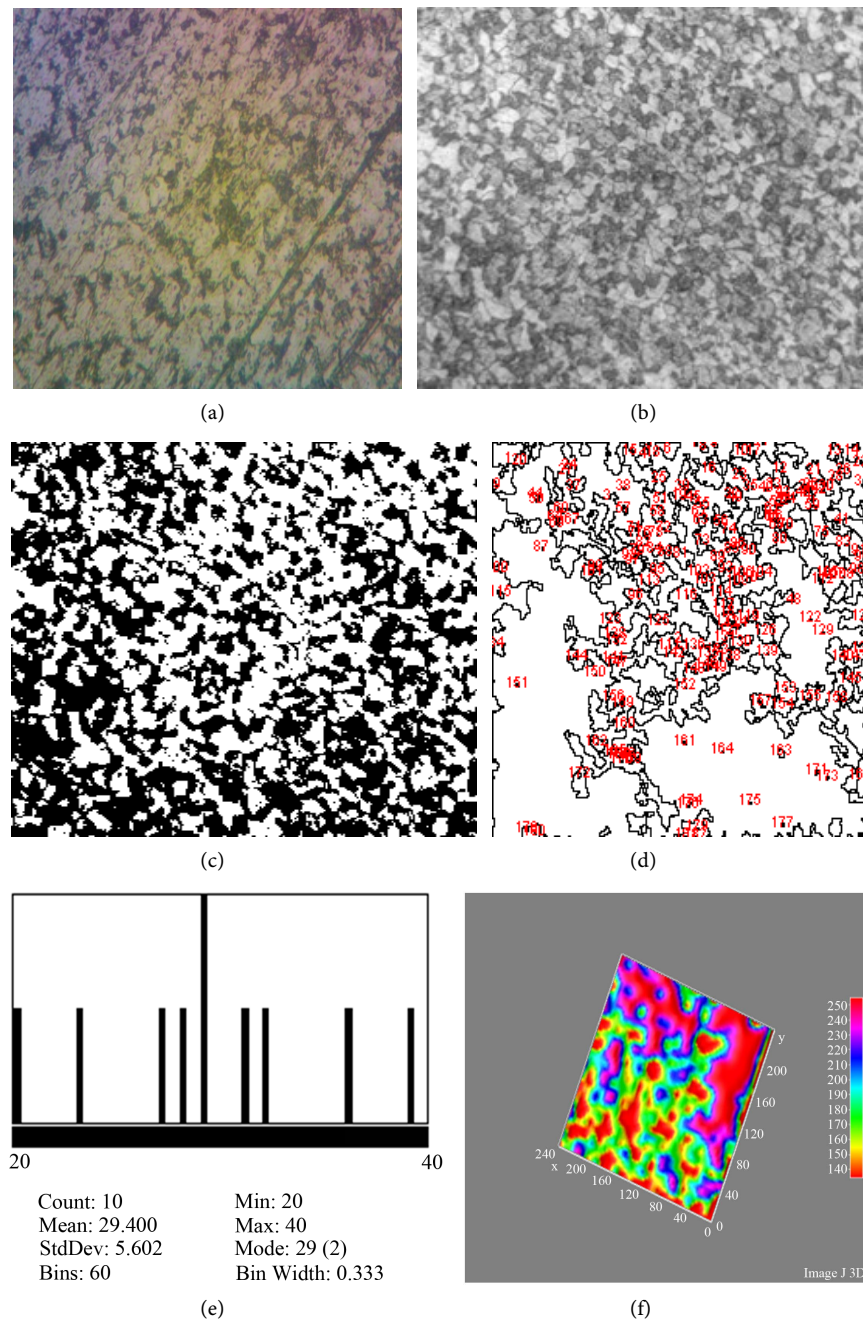
Figure 4. Processed image of 900°C annealed steel by image analysis (using) Image J. (a) Original image - Optical Microscope; (b) processing and threshold (blue); (c) thresholded (black and white); (d) result of particle distribution (using analysis tool in Image J); (e) Area distribution of the grains; (f) Interactive 3D surface plot.

4. Conclusions

In this study, we have successfully analyzed some basic parameters of 0.17% C of HSLA Steels, such as the circularity, ferret angle, solidity and perimeter, average area and the percentage area using image J.

It also showed the differences in the images of the six annealed samples. The method is automated and very reliable and accurate, very fast and can be used
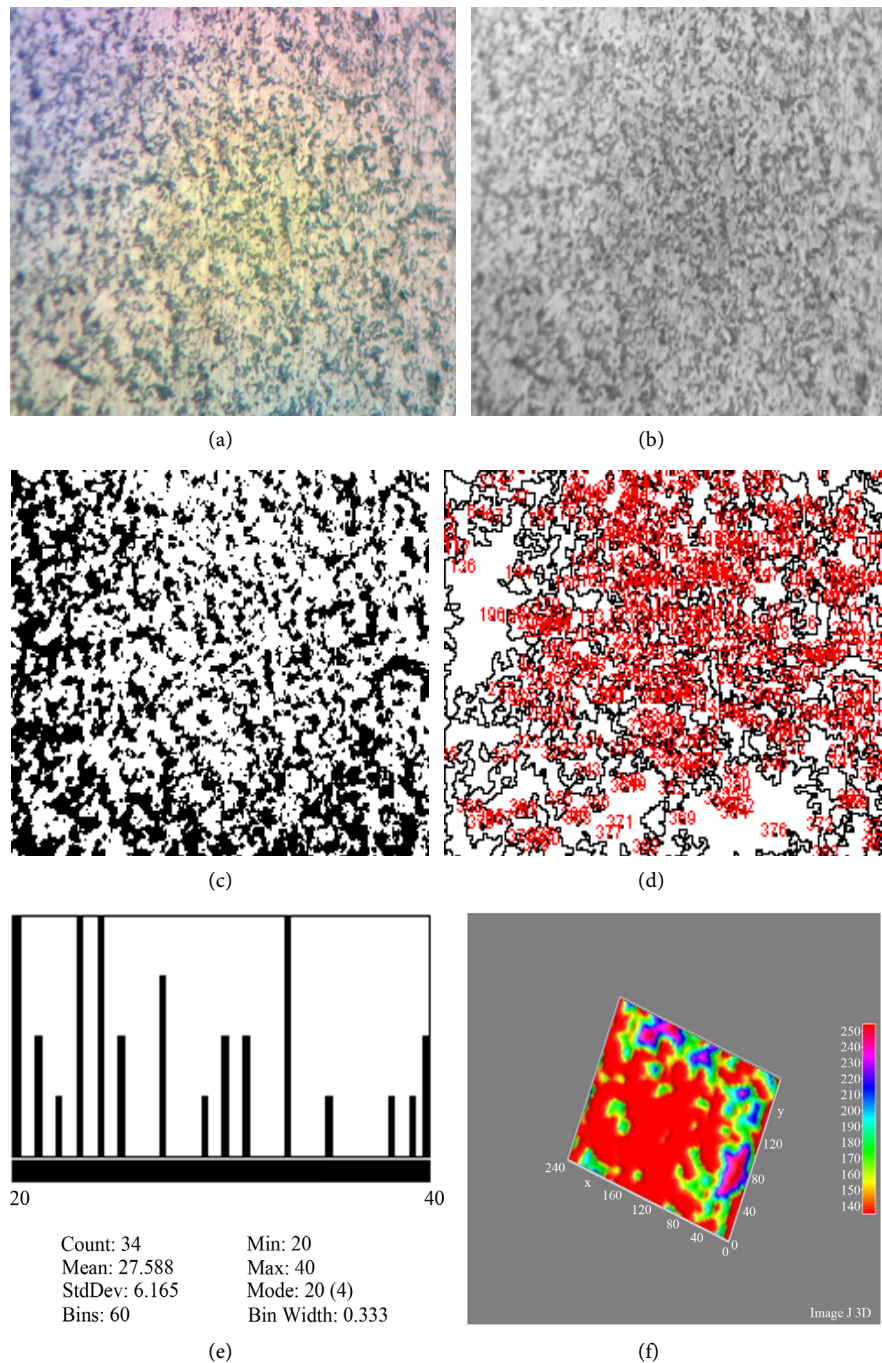
Figure 5. Processed image of 930˚C annealed steel by image analysis (using) Image J. (a) Original image - Optical Microscope; (b) processing and threshold (blue); (c) thresholded (black and white); (d) result of particle distribution (using analysis tool in Image J); (e) Area distribution of the grains; (f) Interactive 3D surface plot.

for some sundry analysis. From the mechanical analysis result, the annealed sample at 840˚C has a highest hardness value of 129.4 BHN and an impact value of 58.75 J. It was observed that at 870˚C annealing temperature, the hardness value decreased to 125.2 BHN while the impact value increased to 60.56 J; 900˚C gave a hardness value of 121.7 BHN and impact value of 62.05 J; 930˚C
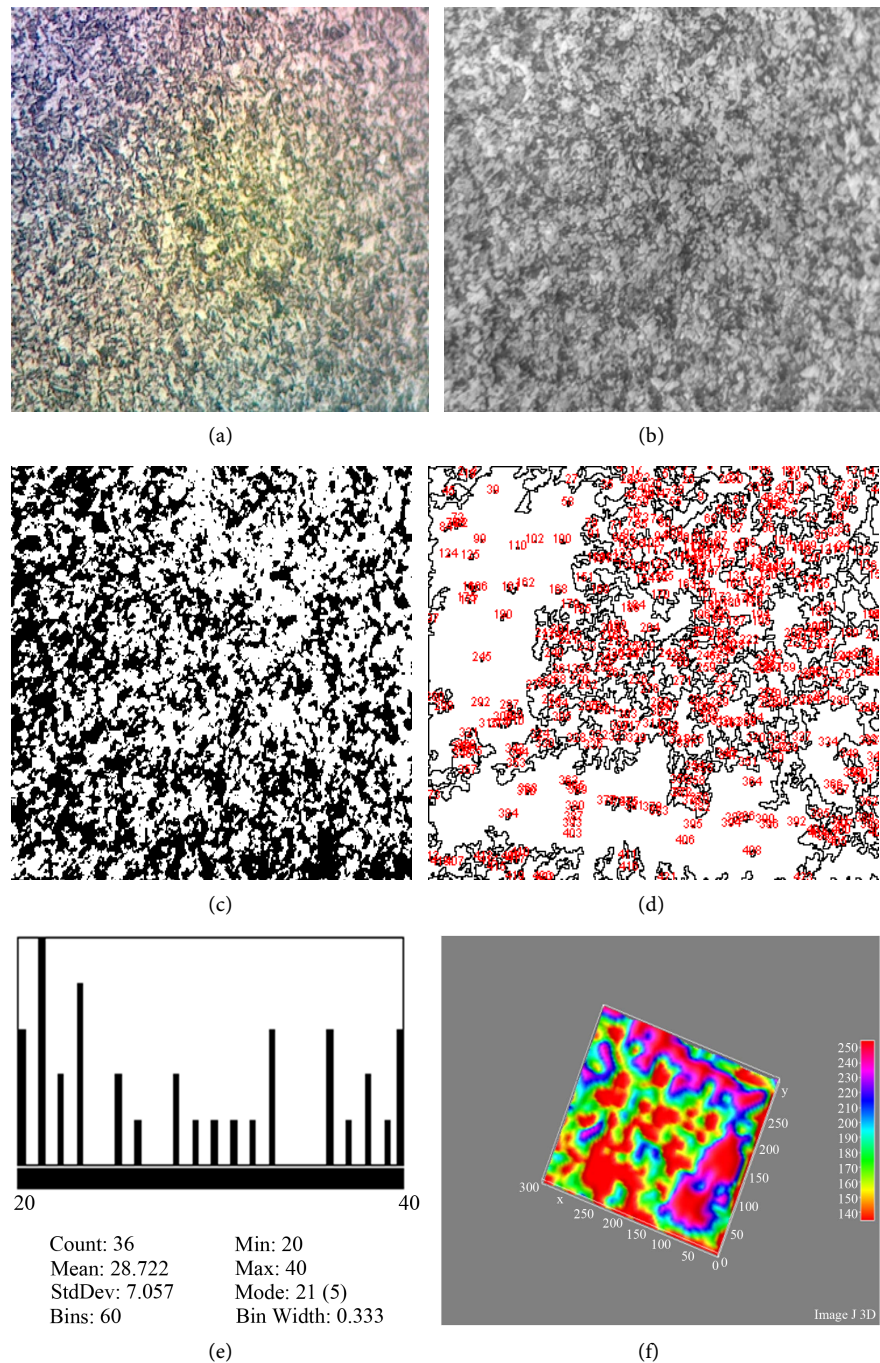
Figure 6. Processed image of 960˚C annealed steel by image analysis (using) Image J. (a) Original image - Optical Microscope; (b) processing and threshold (blue); (c) thresholded (black and white); (d) result of particle distribution (using analysis tool in Image J); (e) Area distribution of the grains; (f) Interactive 3D surface plot.

has a hardness value of 121.7 BHN and impact value of 63.76 J; at 960˚C the hardness value is 120.8 BHN while the impact value increased to 64.80 J. At 990˚C, we had the least value of hardness value of 118.6 BHN and highest impact value of 66.65 J, which means that annealing enhanced the fatigue property and tensile strength (wear strength) of the steel in study.
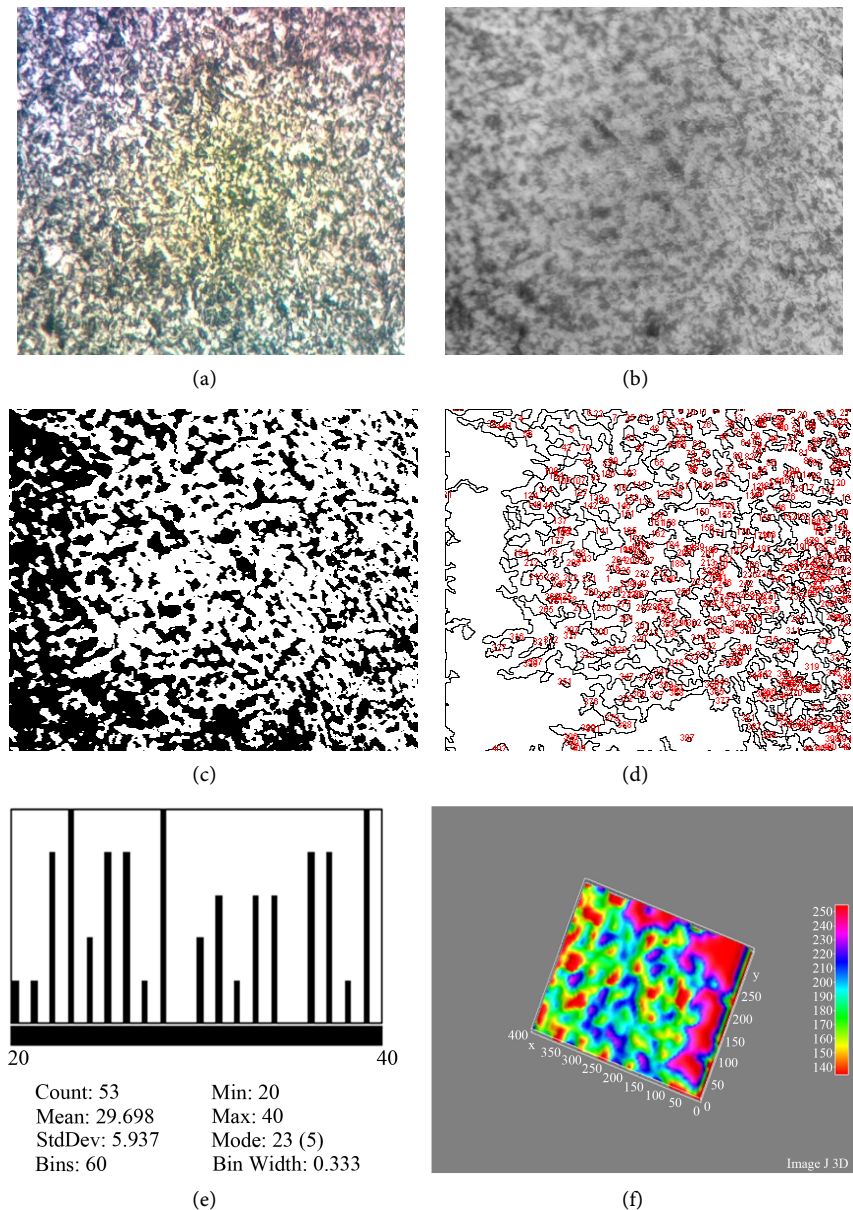
Figure 7. Processed image of 990˚C annealed steel by image analysis (using) Image J. (a) Original image - Optical Microscope; (b) processing and threshold (blue); (c) thresholded (black and white); (d) result of particle distribution (using analysis tool in Image J); (e) Area distribution of the grains; (f) Interactive 3D surface plot.
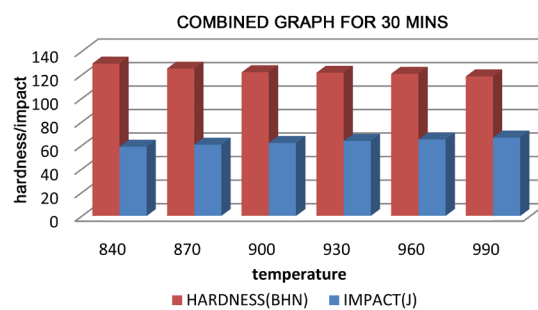

Figure 8. Impact and hardness test for 30 mins soaking time of 0.17% C HSLA steels.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Sreeteja, M., Pranavadithya, S., Nitish, V. and Sowmya, G. (2017) Experimental Investigation on the Effect of Annealing on Fatigue Life of SAE 202 and 440C Steels. *International Journal of Current Engineering and Technology*, **7**, 857-861.

[2] Hu, J.Z., Wang, S.M., Zhao, X.L. and Yu, B.T. (2010) Structure and Performance of Welding Structure and Performance of Welding Joint of Q235 Steel Welded by SHS Welding. *Mechanical Engineering in China*, **5**, 189-193.
https://doi.org/10.1007/s11465-010-0003-3

[3] Zhao, Z., Wu, H., Peng, C., Sun, B., Guo, B., Liang, J. and Tang, D. (2017) Mechanical Behavior of Two Materials. *Proceedings of the* 18*th International Congress of Mechanical Engineering*, Ouro Preto, 6-11 November 2017.

[4] Policena, M.R., Trindade, A., Fripp, W.H., Israel, C.L., Fronza, G. and João de Souza, A. (2019) Fatigue Failure Analysis of HSLA Steel Sheets Holed by Conventional and Flow Drilling Processes. *Revista Matéria*, **24**.
https://doi.org/10.1590/s1517-707620190003.0784

[5] Jia, D., Ramesh, K.T. and Ma, E. (2003) Effect of Monocrystalline and Ultrafine Grain Sizes on Constructive Behaviour and Shear Bands in Iron. *Acta Materialia*, **51**, 3495-3509. https://doi.org/10.1016/S1359-6454(03)00169-1

[6] Vervynckts, S., Thibamx, P. and Verbeken, K. (2012) Effect of Niobium on Microstructure and Mechanical Properties of Hot Rolled Micro alloyed Steels after Recrystallization-Controlled Rolling. *Metals and Materials International*, **18**, 37-46.
https://doi.org/10.1007/s12540-012-0005-2

[7] Bhadesia, H.K.D.H and Honeycombe, R.W.K. (2006) Steel: Microstructure and Properties. 3rd Edition, Butterworth-Heinemann, Oxford.

[8] Dzupon, M., Parilak, I., Kollarova, M. and Sinaiova, I. (2006) Dual Phase Ferrite-Martensitic Steel Micro Alloyed with V-Nb. *Metalurgija*, **46**, 15-20.

[9] Kadkhodapour, J., Butz, A. and Rad, S.Z. (2011) Mechanisms of Void Formation during Tensile Testing in a Commercial, Dual-Phase Steel. *Acta Materialia*, **59**, 2575-2588. https://doi.org/10.1016/j.actamat.2010.12.039

[10] Arasu, T.P., Dhansekaram, R., Kumar, S.P. and Srinivasan, N. (2013) Effect of Hardness and Microstructure on En 353 Steel by Heat Treatment. *International Journal of Engineering and Science*, **2**, 1-5.

[11] American Society for Metals (ASM) (2001) Alloying: Understanding the Basics. Ferrite-Martensite Dual-Phase Steels over a Broad Range of Strain Rates. Metals International, Materials Park, Ohio. http://www.asminternational.org/

[12] Schneider, C.A., Rasband, W.S. and Eliceiri, K.W. (2012) NIH Image to ImageJ: 25 Years of Image Analysis. *Nature Methods*, **9**, 671-675.
https://doi.org/10.1038/nmeth.2089

[13] Dang, A.T., Vo, T.T. and Le, V.P. (2014) Analyzing 2D structure Images of Piezoelectric Ceramics Using ImageJ. *International Journal of Materials and Chemistry*, **4**, 88-91.

[14] Miroslaw, S., Winiarski, G., Wójcik, Ł. and Bulzak, T. (2020) Effect of Annealing Time and Temperature Parameters on the Microstructure, Hardness, and Strain-

Hardening Coefficients of 42CrMo4 Steel. *International Journals of Microstructures and Mechanical Properties of Alloy*, **13**, 2022. https://doi.org/10.3390/ma13092022

[15] Senthil, S., Pradeep, S., Senthamaraikannan, P., Sanjay, M. and Mohammad Jawaid, P. (2018) Characterization and Properties of Natural Fiber Polymer Composites: A Comprehensive Review. *Journal of Cleaner Production*, **172**, 566-581. https://doi.org/10.1016/j.jclepro.2017.10.101

[16] Al-Qawabah, S.M.A., Nabeel Alshabatat, U.F. and Al-Qawabeha, G. (2012) Effect of Annealing Temperature on the Microstructure, Microhardness, Mechanical Behavior and Impact Toughness of Low Carbon Steel Grade 45. *International Journal of Engineering Research and Applications* (*IJERA*), **2**, 1550-1553.