IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 3 Ver. II (May - Jun. 2015), PP 178-183
www.iosrjournals.org

Effect of Brine Solution on Grain Size Formations in AISI 1080 Low Carbon Steel

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Abstract: *This paper presents the influence of (AISI 1080) carbon steel samples quenched in brine solution of concentrations 3.5, 5.5 and 8.0 mol/dm^3 under condition of constant bath temperature. The growth, formation and distribution of grain sizes in the microstructures of the quenched samples were analyzed using fractal analysis. Increase in brine conc. was found to favor the growth and distribution of grain sizes. In the as-cast sample, the grain sizes are very small having the sphericity values (β) within the range of 0.3 to 0.6. However, the grain size distribution map for sample cooled in 5.5 mol/dm^3 of brine have better regular shapes with weighted average values of sphericity and fractal dimension; β = 0.8386 and D = 1.0947. Increase in concentration of brine above 5.5 mol/dm^3 further reduces the fractal dimension of the steel from attaining the perfect shapes and sizes.*

Keywords: *Name of steel, Brine, Grain size, Sphericity, Fractal dimension.*

I. Introduction

Heat-treatment is a multi-parameters process which is commonly used metallurgical industries (Çalik 2009; Adedayo et al. 2014). The main goal of heat treatment of steel is to achieve the desired combination of mechanical properties when subjected to controlled heating and cooling system. Quenching on the other hand, can improve the performance of steel greatly. But an important side effect of quenching is the formation of thermal and transformational stresses that cause changes in size and shape which may result in cracks and sudden failure (Al-Qawabah et al. 2012). Therefore, the technical challenge of quenching is to select the quenchant medium and process that will minimize the various stresses developed within the part to reduce cracking and distortion while at the same time providing heat transfer rates sufficient to yield the desired as-quenched properties such as hardness and tensile strength (Krielaart et al. 1996; Lemmadi et al. 2013). There are a wide variety of quenchants use in industries including water, mineral and vegetable oils, aqueous polymers, salt baths and fluidized beds. Water and oil are the quenchants most commonly used to harden steel because they are readily available. Water quenching is apparently much faster than oil quenching; therefore there is possibility of distortion and internal micro-crack after quenching. This makes oil quenching more common (Çalik 2009; Oyetunji and Adeosun 2012; Adedayo et al. 2014). The cooling abilities vary from one quenchant to another. Therefore, it is critical to characterize how the physical and chemical properties of oils and other quenchants might affect their quenching performance as well as the fluid flow within the quench medium. In this study, brine of different concentrations (mol/dm^3) were prepared and used as the quenching medium.

II. Experimental Procedure

In this study, low carbon steel **(AISI 1080)** was purchased from Federal Institute of Industrial Research (FIIRO) Oshodi, Lagos, Nigeria. The steel was cut into three parts of the same size with dimension 80mm long, 50mm width and 0.5mm thick. Table 1 shows the composition analysis of the samples prepared while Figure 1 shows the macrostructures of the samples quenched in brine.

Table 1: Chemical composition of the studied samples (wt. %)

C	Si	Mn	Cr	Ni	Mo	Al	Cu	Pb	S	P	Fe
0.078	0.025	0. 304	0. 017	0.031	0. 0001	0. 015	0. 008	0. 022	0.021	0.0049	99.4

In this study, three different brine solutions composed of salt and sodium chloride (NaCl) of different concentrations 3.5, 5.5 and 8.0 mol/dm^3 respectively were prepared. Each specimen was heat-treated in Muffler furnace **(specification)** at 900º C, holding for 2 hour. The samples were removed and quenched in prepared brine solution and allow cooled for a period of 30 minutes. They were removed, clean and later view under the optical metallurgical microscope XJL-17 model. Hardness measurements with Leitz 8299 micro-hardness tester and impact test (**specification**) were carried out following ASTM E8M-91 standard.

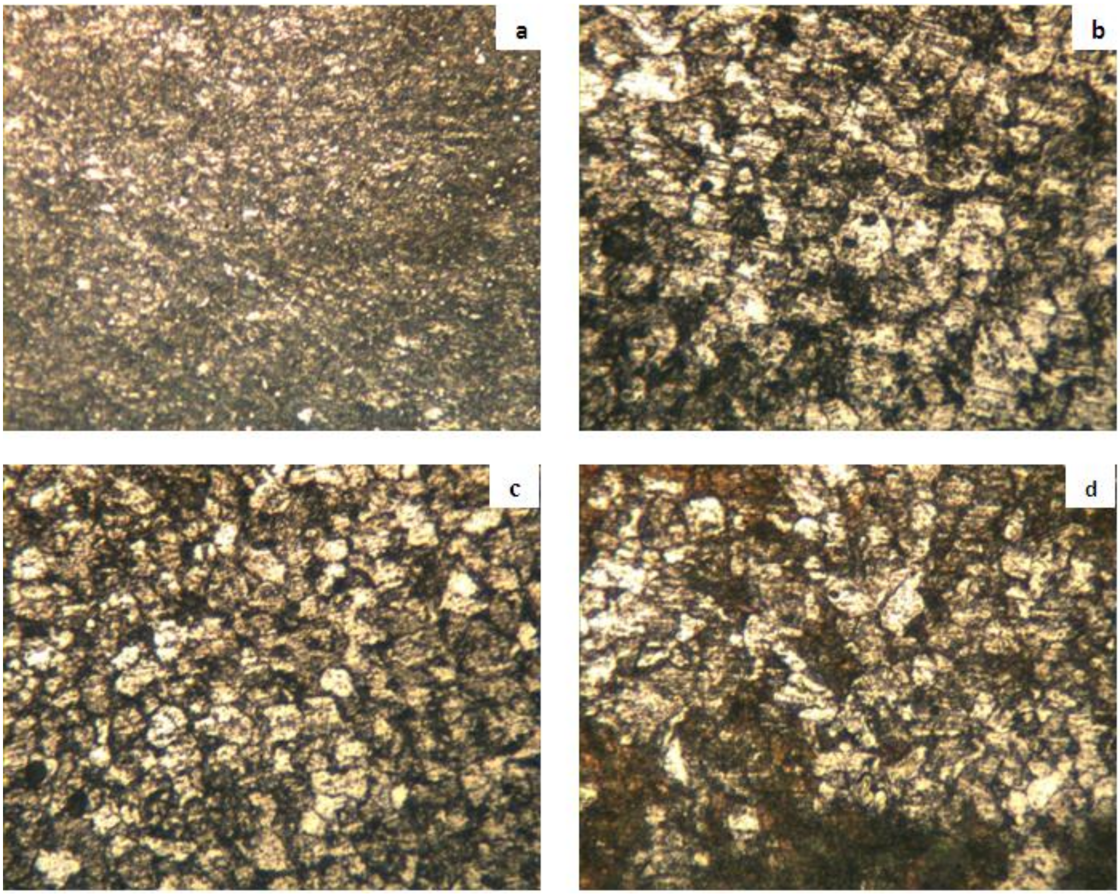


Figure 1: Microstructure of specimen quenched in brine with different concentration (a) as-cast sample (b) 3.5 molar conc. (c) 5.5 molar conc. (d) 8.0 molar conc.

III. Methodology

3.1 Fractal Approach of Grain size Characterization

Fractal geometry was firstly developed by Mandelbrot (1983). Its principle is universal in any measurement and has been previously used by many researchers to numerically describe complex microstructures including graphite flakes, nodules and pores (Lu and Hellawell 1995, Huang and Lu 2002; Hangai and Kitahara 2008; Kong et al. 2011; Durowoju and Akintan 2013). The mathematical basis for measuring chaotic objects with the power law is adopted in this work. The basic equation is as follows:

$$P = P_e\, \delta^{D-1} \qquad (1 < D < 2 \text{ and } \delta_m < \delta < \delta_M) \qquad (1)$$

where "P_e" is the measured perimeter, "P" is the true perimeter, "δ" is the yardstick, "δ_m and δ_M" are the upper and lower limits respectively for any shape and "D" is defined as the fractal dimension. The fractal dimension "D" describe the complexity of the contour of an object which can be more practically called roughness. Sphericity "β", on the other hand is used with fractal dimension "D", to describe the shape of the grain sizes formed (Durowoju and Akintan 2013; Mandelbrot 1983). It can be expressed as:

$$\beta = 4\pi A_T/P^2 \qquad (0 < \beta < 1 \text{ and } 1 < D < 2) \qquad (2)$$

From the above two equations:

$$\beta = (4\pi A_T/P^2)\, \delta^{2(1-D)} \qquad (0 < \beta < 1 \text{ and } 1 < D < 2) \qquad (3)$$

where "A_T" is the total grain size area. When $\beta = 1$ and $D = 1$, a perfect circular shape is formed by the grain in the microstructure. As β decreases, the shapes become more elongated showing a departure from perfect sphere.

In this work, an interactive MATLAB program was developed to obtain the numerical values of the fractal dimension "D" and the sphericity "β". To develop the program the box counting method was used with a counter incorporated into the program and the small boxes or pixels occupied by the grain size outlines were counted. In all, four pixels (2×2 pixels, 4×4 pixels, 8×8 pixels and 16×16 pixels) and four grid sizes (200×200, 100×100, 50×50 and 25×25) were selected. The selections were made for better resolution and to obtain accurate results. The grain size distribution map (Figure 2) and the spatial point pattern method (Figure 3) and (Huang and Lu 2002) were used to describe the patterns displayed by the grain sizes after qeunching. The grain size distribution map can further be used to identify the shapes of the grains and their dispersion from regular shapes.

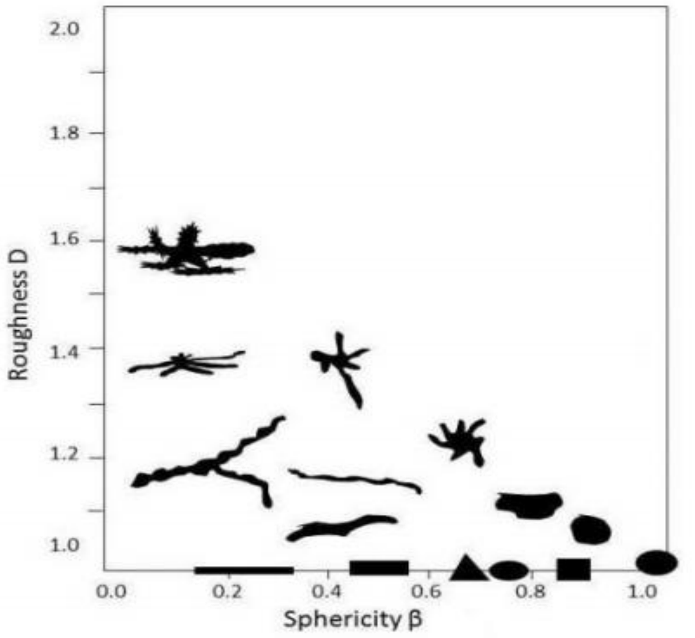


Figure 2: Illustration of development of irregular shapes based upon Euclidean circle or rectangle.

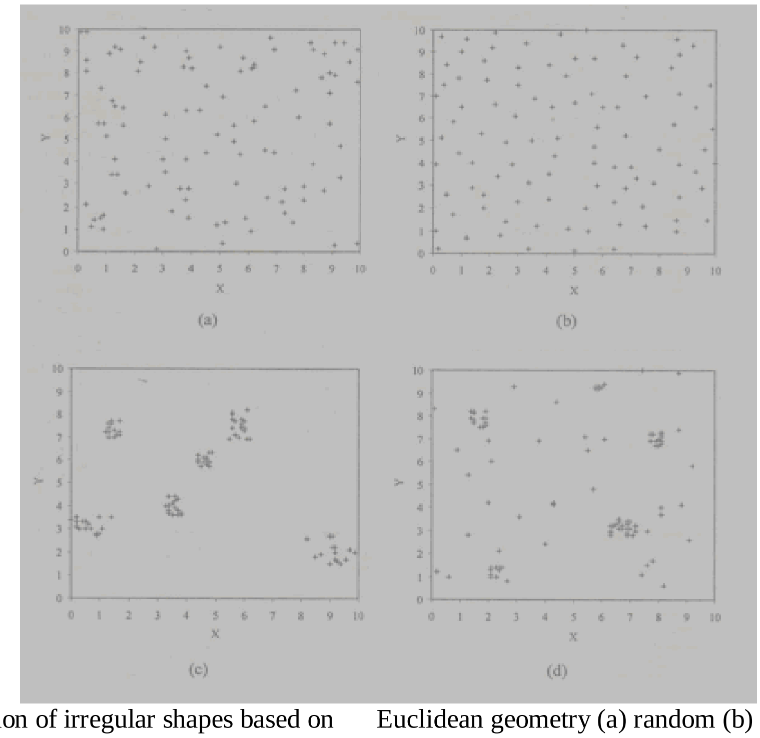


Figure 3: Illustration of irregular shapes based on Euclidean geometry (a) random (b) regular (c) clustered (d) clustered superimposed on random background (Lu and Hellawell 1995).

IV. Result And Discussion

Figure 4 shows the graph of impact and hardness test against the brine concentration after the heat-treatment. It was observed that there is gradual increment in the impact and hardness values of the sample as the concentration of brine increases.

Presented in Figures 5 (a - d) are the resulting fractal analysis depicting the variation and distribution of grain sizes within the micrograph for samples heat-treated at 900º C and cooled in brine of three different concentration while Figures 6 (a - d) show the grain size distribution map for each of the sample. In Figure 1a, it was observed that the grain sizes are very small. This is evidence from grain size distribution map shown in Figure 6a in which the sphericity values (β) lies within the range of 0.3 to 0.6. The weighted average values of 0.4244 and 1.2817 for sphericity and fractal dimension were obtained. The grain sizes are said to be clustered.

Also shown in Figure 6b, is the grain size distribution map for sample cooled in 3.5 mol/dm^3 of brine. The weighted average values of 0.3002 and 1.2851 for sphericity and fractal dimension were obtained. The weighted average values of 0.3149 and 1.2817 for sphericity and fractal dimension were obtained. The grain sizes are clustered superimposed on random background.

Also presented in Figure 6c, is the grain size distribution map for sample cooled in 5.5 mol/dm^3 of brine. The grain sizes are seen to have almost attained regular shapes with weighted average values of (β = 0.8386 and D = 1.0947). The grain sizes are said to be clustered superimposed on random background. However, increase in brine concentration seems not favour the shapes and distribution of grain sizes (sphericity) in that the weighted average value β = 0.6294 was obtained. Indeed, it was expected that the values should be closer to 1 and the distribution should be regular in relation with Figure 2 and 3.

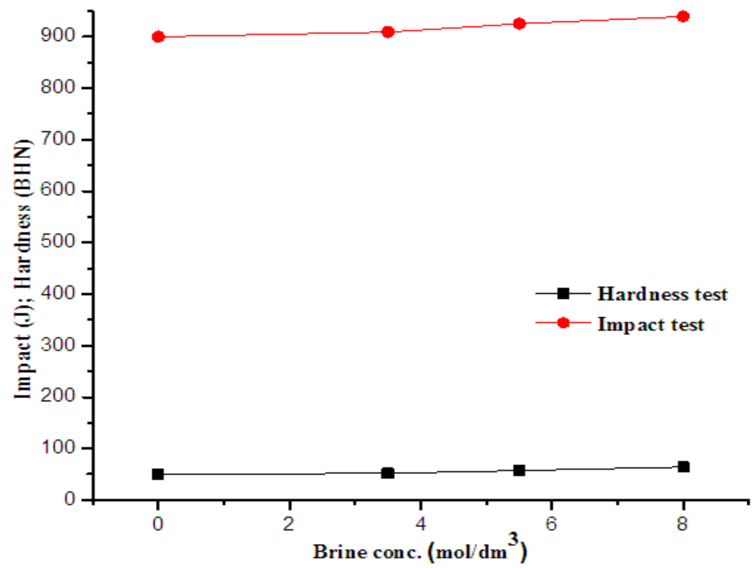
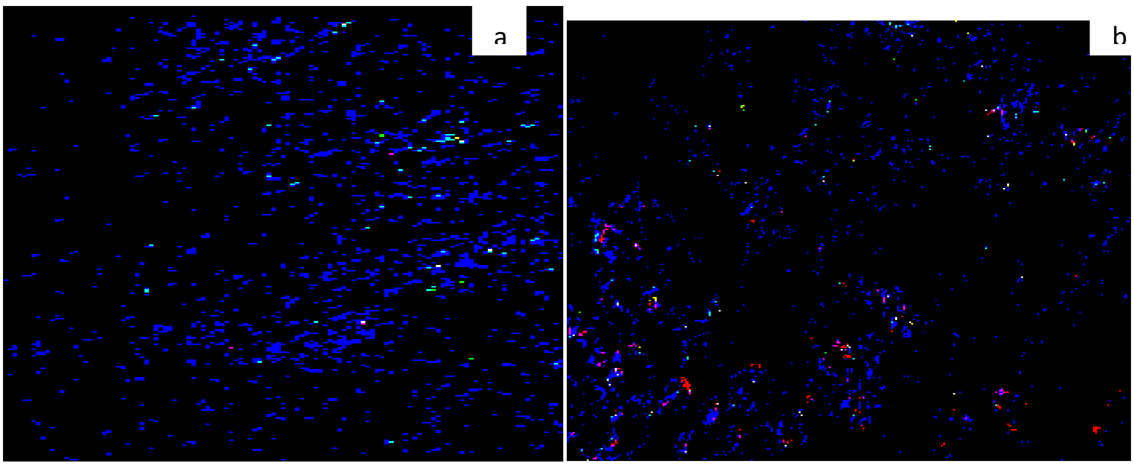


Figure 4: Variation of Impact test (J) and Hardness (BHN) against Brine conc. (mol/dm^3)



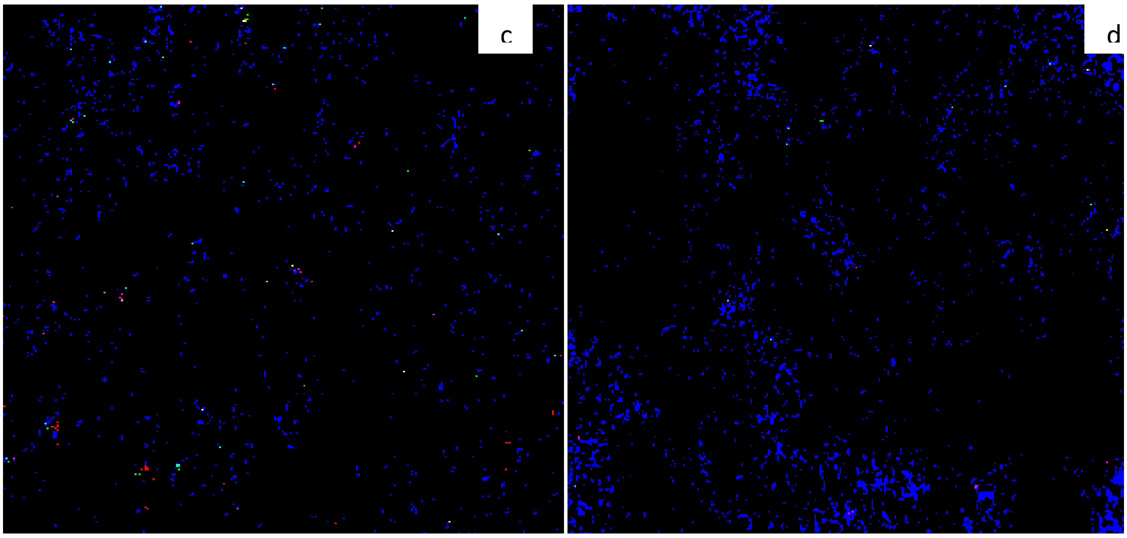


Figure 5: Fractal analysis of the samples depicting various degrees of grain sizes in (a) as-cast sample (b) 3.5 molar conc. (c) 5.5 molar conc. (d) 8.0 molar conc.

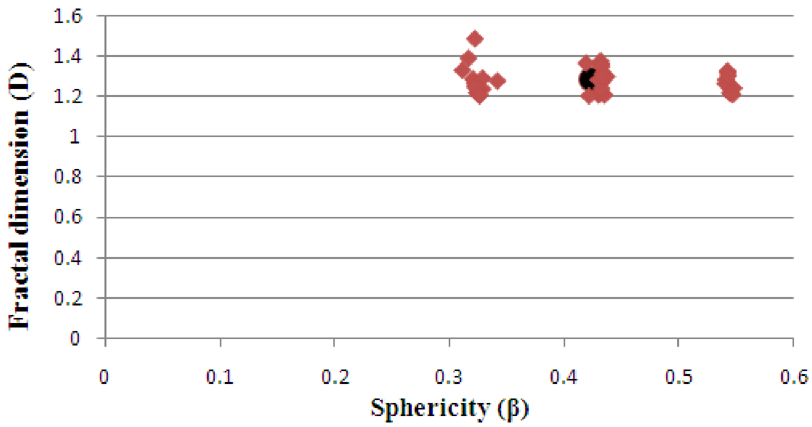


Figure 6a: Grain size distribution map for AISI 1080 for as-cast sample

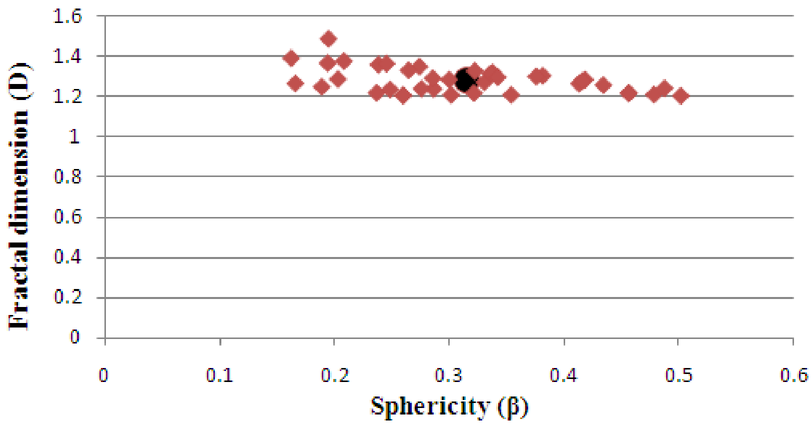


Figure 6b: Grain size distribution map for AISI1080 cooled in 3.5 mol/dm^3 brine solution

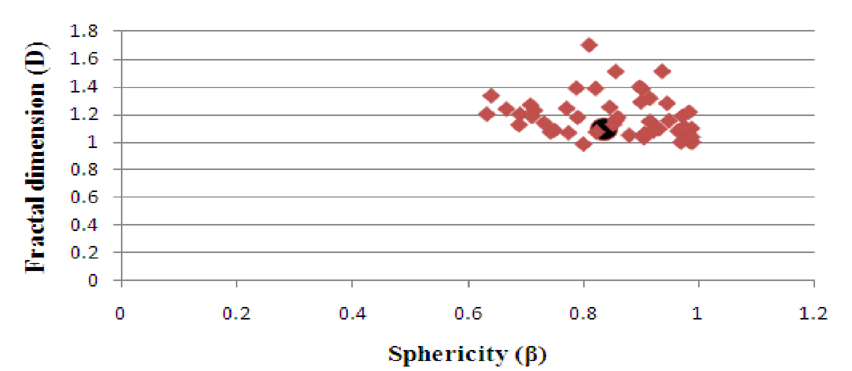


Figure 6c: Grain size distribution map for AISI1080 cooled in 5.5 mol/dm^3 brine solution

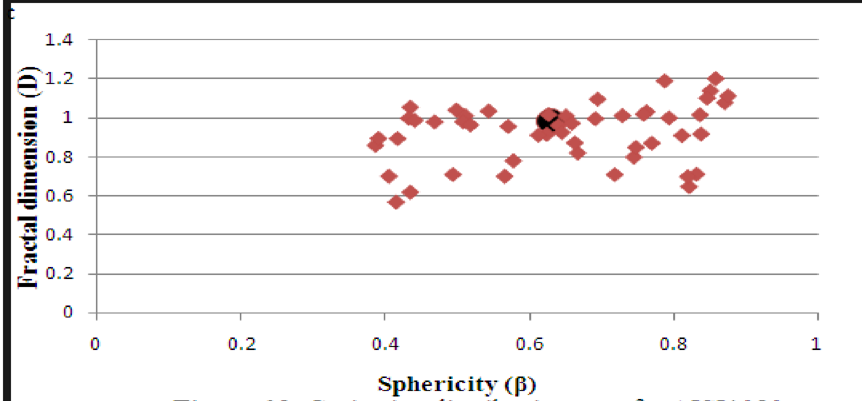


Figure 6d: Grain size distribution map for AISI1080 cooled in 8.0 mol/dm^3 brine solution

V. Conclusion

The quantitative estimation of grain size distribution in AISI 1080 has been conducted to identify how the uses of brine as a quenching medium can favour the growth and distribution of grain sizes in AISI 1080**.** The complexity of the perimeter of individual grain sizes and the spatial distribution of the grains were quantified by fractal analyses. The validity of this method shows that brine solution of 5.5 mol/dm^3 (1 dm^3 of distilled water and 5.5 mole of NaCl) possesses better sphericity and fractal dimension.

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