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Fatigue Behaviour of Medium Carbon Steel of Different Grain Structures

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Abstract
This paper investigated the effect of heat treatment operations on the fatigue resistance of low carbon steel. Specimens after preparation for fatigue testing were subjected to annealing, normalizing and quenching heat treatment. Results show that the annealed specimen had the largest number of cycles to failure, indicating a high fatigue resistance. The microstructure of the specimens was examined in other to corroborate the obtained property with the microstructure. When compared with the untreated specimen, the annealed specimen (with optimum fatigue resistance) shows a large grains size of pearlite which was distributed across the entire surface of the microstructure. Generally, it was found that the size and distribution of specimens' grains affect the resistance of the low carbon steel to fatigue failure.
Keywords: fatigue, low carbon steel, heat treatment, microstructure

1. Introduction
Majority of engineering designs, structures, machines, and systems involve materials analysis, selection and categorization. These engineering materials are numerous and among them are metals, composites, ceramics and plastics. The most useful one being metals due to their mechanical properties like tensile and compressive strength, ductility, brittleness, fatigue strength and others. Among these metals, low carbon steel has a very high status in terms of its versatility, cheapness, ease and low cost of production which makes it the most widely used metallic material. The mechanical properties (and some other properties like electrical, chemical) form the major characterization and categorization of metals and also determines the type of material needed for certain specific engineering purposes. Hence due to the suitability of metals for very wide range of applications, the need to study and establish certain facts regarding metals arises.

Metallic materials consist of a microstructure of small crystals called grains or crystallites. The grain sizes and composition which make up the nature of the grains are one of the most effective factors that determine the overall mechanical behaviors (hardness, tensile strength, toughness, wear resistance) of metals (Qamar, 2009). An efficient way to manipulate the properties of metals via grain structure manipulation by controlling the rate of diffusion and that of cooling is that of heat treating procedures. In other words, heat treatment systematically alters the microstructural arrangements and sizes of the metals grains which are the reasons for the changes observed in mechanical properties of metals after heat treatment operations (Totten, 2007). Some properties of the steel might be required to be varied due to design specifications and requirements. This is mostly done by various heat treatment operations (Daris and Oelmann, 1983).These heat treatments give the desired properties of carbon steel, but sometimes at the expense of some other properties.

Hence, before selecting a type of heat treatment, various factors need to be considered including the type of loading the materials will be subjected to in the service conditions. Of the various loading types is fatigue loading which is a load whose magnitude varies with (or is a function of) time. Hence, using fatigue loading as a case study, it would be observed that different materials fail at different load cycles and this character can be directly traced to the different grain structures, sizes and orientation of the materials.

2. Materials and Method
The chemical composition of the as-received specimen is presented in Table 1. The specimens were prepared for fatigue test by machining on a lathe machine. The specimens were then subjected to annealing, normalising and quenching. In the annealing operation specimen were heated to an austenizing temperature of 850°C±5°C, soaked for 20 minutes in order to attain uniform heat distribution and left to cool in the muffle furnace (Power – 5kW, Phase – 1, Weight – 55kg, Temperature – 1200°C, Voltage – 220V, Dimension of chamber – 300x200x120mm). Similar operation was carried out during normalizing and quenching operation except that the specimens after heating were cooled in air and quenched in silica sand respectively. Fatigue test was done with is an Avery Denison type with serial no 7300. Grips are provided for torsion tests and for bend tests on flat specimen. Standard microstructural test pieces (as-received and heat treated) were prepared and ground using emery paper with grit 220 to 600 microns in succession. The ground surface was polished using a mixture of alumina and diamond paste and then etched in a solution containing 2 ml Nitric acid and 100 ml Ethanol. The etched surfaces were left for 20 seconds before they were rinsed and dried. The specimens' crystals morphology

was viewed under an optical metallographic microscope at 600X magnification and the photomicrographs are shown in Plates1-4.

Table 1. Composition of specimen

Elements	% wt Composition
Iron	99.030
Carbon	0.1164
Silicon	0.0901
Manganese	0.3574
Phosphorous	0.0297
Chromium	0.0231
Nickel	0.0767
Copper	0.1178
Vanadium	0.0010

3. Result and Discussion

3.1 Effect of Heat Treatment on the Microstructure of Specimens

Plate 1 shows a uniform distribution of ferrite which are the brightly coloured parts and pearlite (a mixture of ferrite and cementite) which are the dark or black spots and which are congested along the grain boundaries and also slightly dispersed over the ferrite. The grain sizes are moderate and the boundaries appear smooth, apart from the pearlitic presence.

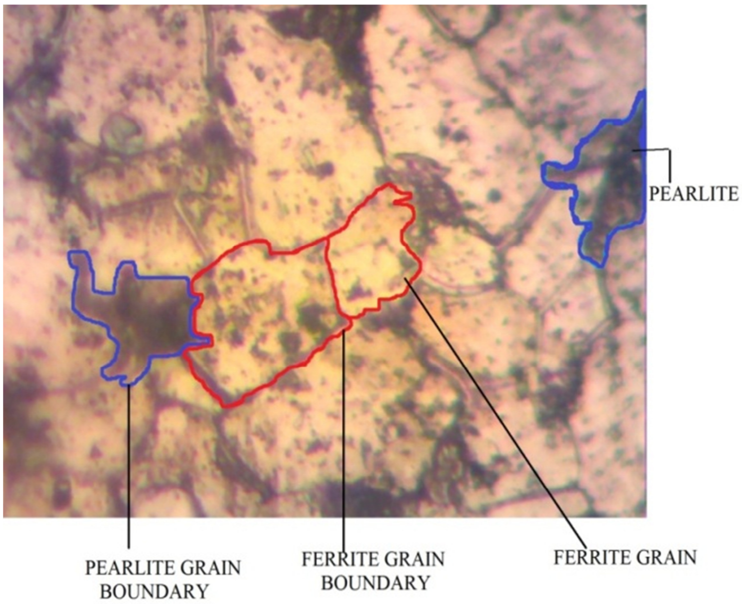

Plate 1: Micrograph Of as-received specimen at X600

Plate 2 is the annealed specimen and the micrograph shows a large grain size of pearlite which was distributed across the microstructure. Unlike the untreated specimen, the pearlite phase which was congested along the grain boundaries is now distributed across the entire surface of the microstructure. The size of the grains makes it easy for dislocation to glide during fatigue loading, hence the high fatigue resistance. Annealed materials are usually ductile and stress free due to these stated characteristics. In addition, when a crack or void forms in a pearlitic matrix, it will tend to run along the length of a pearlite lamella. Examining thistype of fracture under the SEM reveals that the base of the dimples contain fractured pearlite lamella (Scott, 2008)

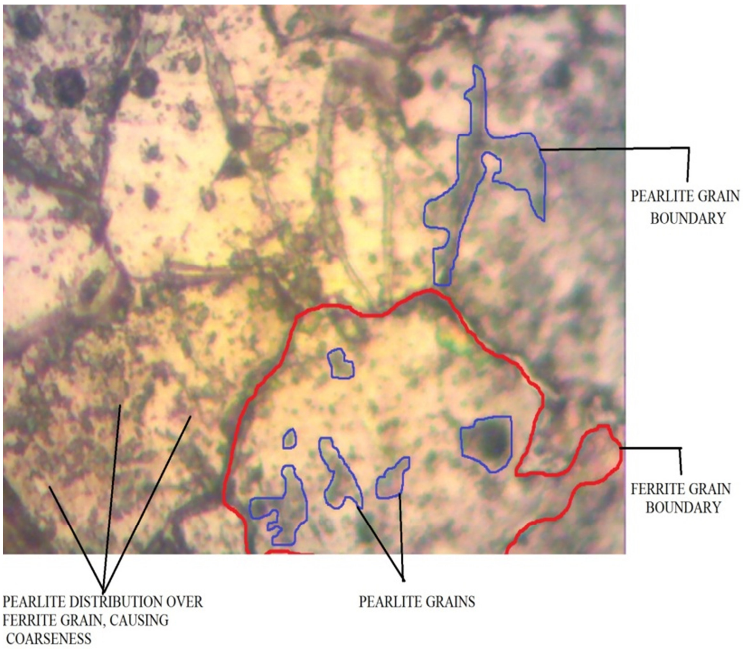

Plate 2: Micrograph of Annealed Specimen at X600

When compared to the annealed sample, the micrograph of the normalized sample (Plate 3) shows a relatively smaller grain size and a balanced distribution of ferrite and pearlite with uniform fine grain and quite similar to the control specimen, but appears relatively better than annealed and control samples

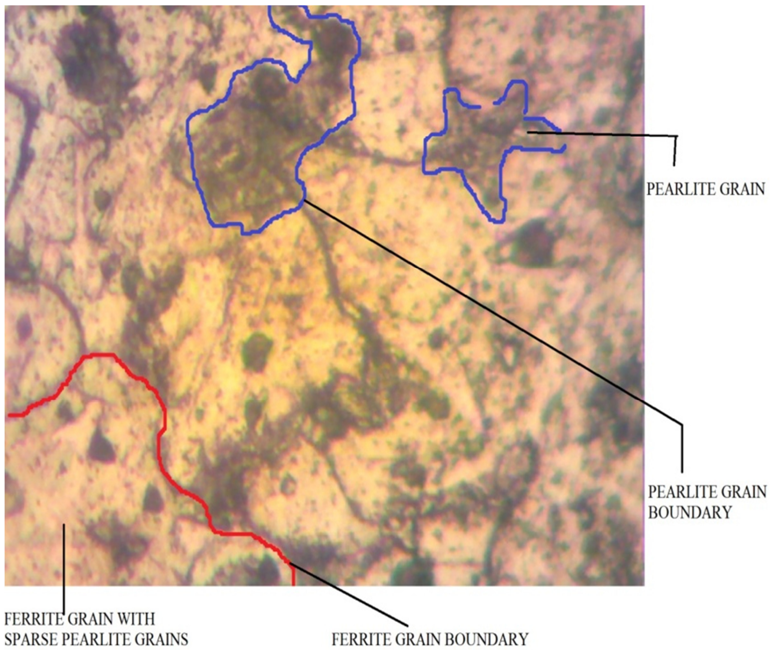

Plate 3: Micrograph of normalised specimen at X600

In addition, the sand cooled specimen shows a fine and relatively smaller ferrite and pearlite distribution and has a relatively lower amount of pearlite concentration as observed in the control and annealed specimen and it is observed that the grain boundaries appear thin and congested (Plate 4).

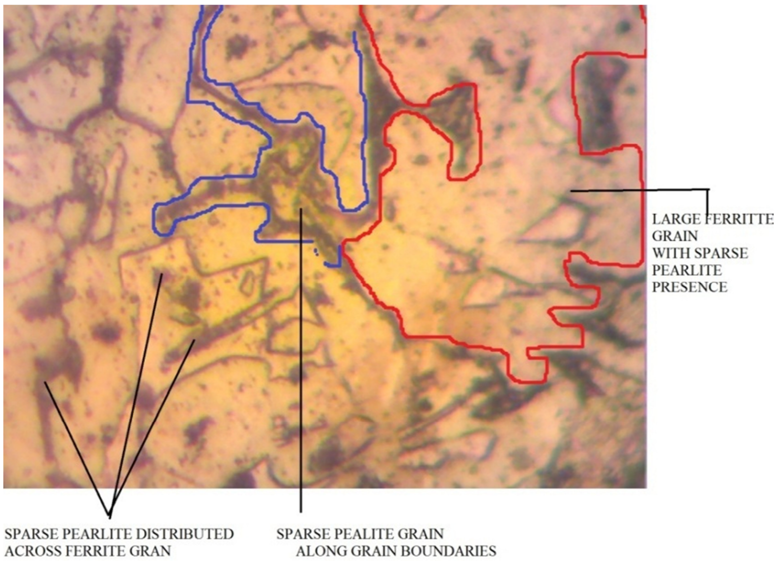

Plate 4: Micrograph of silica quenched specimen at X600

3.2 Effect of Heat Treatment on the Fatigue Property of Specimens

As seen from the results from graphs (Figure 1-4), a significant variation in the no. of cycles to failure was observed with respect to all the tested specimens. The annealed specimen had the largest number of cycles to failure, indicating a high fatigue resistance, followed by the specimen that was quenched in silica sand and then the normalized specimen. This agrees with the microstructures of the annealed specimen has it exhibit large and coarse distribution of pearlite (Senthilkumar and Ajiboye, 2012).

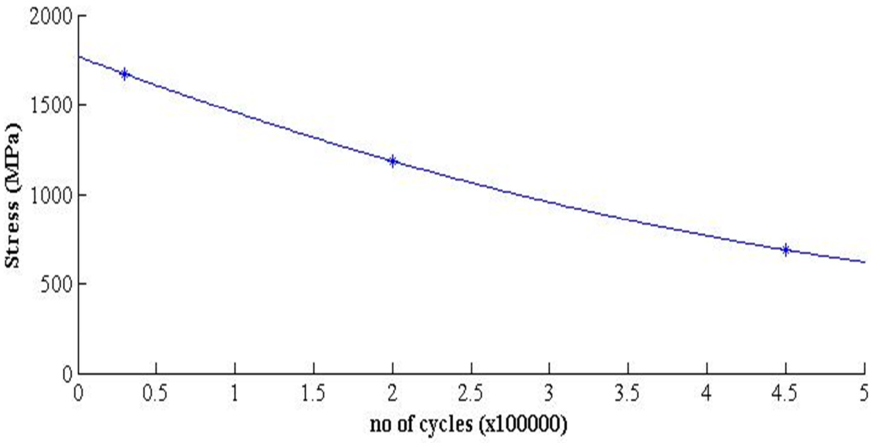

Figure 1: S-N curve for the as-received specimen

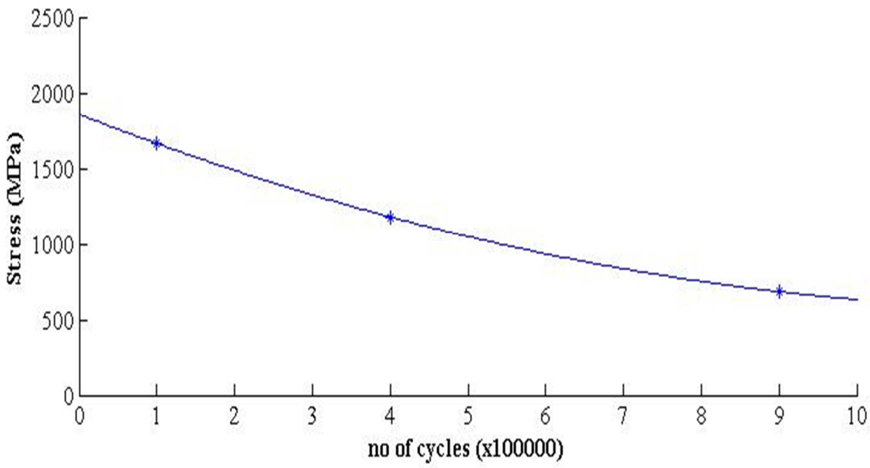

Figure 2: S-N curve for the annealed specimen

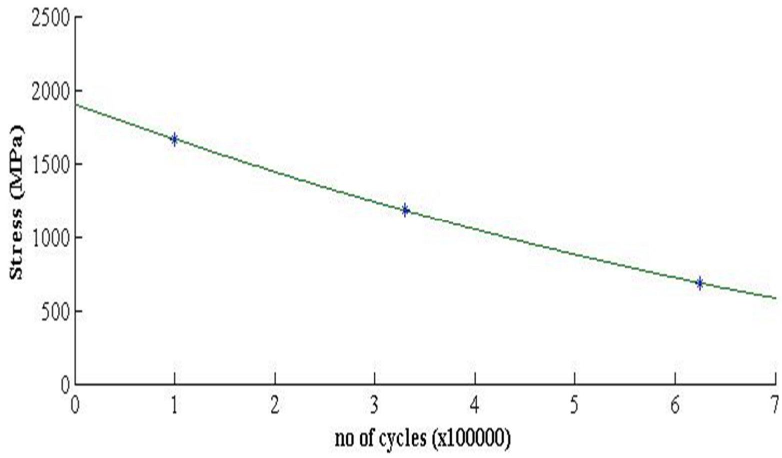

Figure 3: S-N curve for the normalized specimen

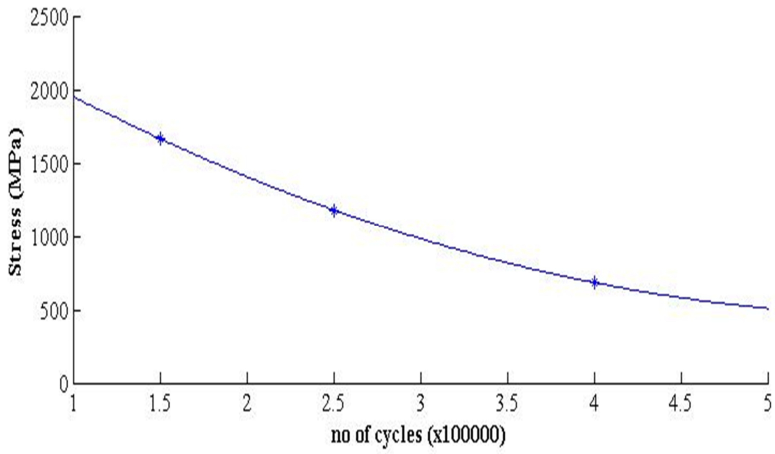

Figure 4: S-N curve for the quenched specimen

4. Conclusion

Heat treatment operation can be used to optimize the fatigue resistance of low carbon steel. The annealed specimen had the largest number of cycles to failure, indicating a high fatigue resistance, followed by the specimen that was quenched in silica sand and then the normalized specimen. The microstructure of the specimens corroborate with the obtained properties. The fatigue behaviour of the specimens was attributed to grain size and distribution. During application in which fatigue property is of optimum importance, annealed specimen which shows a better fatigue resistance is recommended.

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