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Effect of Various Prestrain Levels on the Microstructure of Heat Treated 0.14% Carbon Steel

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Abstract

The effect of various prestrain levels on the microstructure of heat treated 0.14%C steel was analyzed. Low carbon steel was heat treated by first austenitising at 910°C and then quenched in water. The heat treatment process was completed by reheating in the furnace and holding at 700°C. The specimens were then subjected to prestrain levels of 7%, 9%, 13%, and 20% in tension. Microstructural analysis was carried out on specimens for the various prestrain values including the unstrained. The results displayed that the microstructures of the different specimens showed consistent changes with the increasing prestrain values. Thus, the higher the prestrain value the finer the precipitate particles.

1. Introduction

Heat treatment is a process in which materials are subjected to one or more temperature cycles to confer certain desired properties. Heat treatment of steel can also alter the size and shape of grains and micro constituents of the steel. The shape of the grains is altered by heating the steel to a temperature above that of recrystallization, the size of the grains is controlled by the temperature and duration of heating and the speed at which the steel is cooled after heating. Heat treatment is only effective with certain alloys because it depends upon one element being soluble in another in the solid state in different amounts under different circumstance [1].

The structure of a material usually relates to the arrangement of its internal components. In describing the structure of a material, it is important to make a clear distinction between its crystal structure and its microstructure. The term ‘crystal structure’ is used to describe the average positions of atoms within the unit cell, and is completely specified by the lattice type and the fractional coordinates of the atoms (as determined, for example, by X-ray diffraction). In other words, the crystal structure describes the appearance of the material on an atomic (or Å) length scale [2]. The term ‘microstructure’ is used to describe the appearance of the material on the nm-cm length scale [3]. The microstructure can be briefly defined as the arrangement of phases and defects within a material. Microstructures form through a variety of different processes. Microstructures are almost always generated when a material undergoes a phase transformation brought about by changing temperature and/or pressure (e.g. a melt crystallizing to a solid on cooling). Microstructures can be created through deformation or processing of the material (e.g. rolling, pressing, welding etc.). Finally, microstructures can be created artificially by combining different materials to form a composite material such as carbon-fibre reinforced plastic. Microstructure can be observed using a range of microscopy techniques. The microstructural features of a given material may vary greatly when observed at different length scales. For this reason, it is crucial to consider the length scale of the observations you are making when describing the microstructure of a material [3].

Low carbon steel contains between 0.002-0.25% carbon and accounts for a large proportion of the total output of steel. It finds applications in automobiles, tinplate, furniture, refrigerators and for structural purposes like beams, channels and angles for construction [1]. Its low carbon content makes it the most ductile category of steel. It combines moderate strength with excellent ductility and are used extensively for their fabrication properties in the annealed or normalized condition for metal forming, sheet metals applications and structural purposes such as bridges, buildings, cars and ships [4].

Prestrain is the prior plastic deformation of a material [5]. This can be done to improve the strength of the metal by work hardening. When a material does not return to its original dimension upon removal of the applied stress the material is said to have plastically deformed, and this only happens when the applied stress is greater than the yield strength of the material. The degree to which a material can be plastically deformed is dependent on the ductility of the material. Prestraining can also be found to occur during metal forming operations [6]. The prior deformation can occur during various metal working processes like rolling, forging, extrusion, spinning, pressing, drawing, stamping, etc. The dimensional changes that comes with plastic deformation also causes changes in mechanical properties. Prestrain can also occur unintentionally or accidentally like in machine malfunctions, earthquakes etc [7].

[8] researched that prestraining alters the microstructure of low carbon steel by increasing the strain level which results in the elongation and decrease in the sizes of grains. The elongation of the grain's point in the direction of the applied stress and produces a fiber texture in wire drawing and extrusion. Therefore, the aim of this study is to investigate the effect of heat treatment on the microstructural properties on this steel subjected to various prestraining levels, so that adequate measures can be adopted to improve the micro-structural properties when subjected in service; under load bearing capacity

2. Methodology

2.1 Materials

The material used in this study is low carbon steel rods of 0.14%C composition. The low carbon steel was obtained from the Universal Steel Company Plc. Ikeja Lagos State. Spectrometric analysis of the steel was carried out at the laboratory of the company and the chemical compositions is as shown in Table 1.

2.2 Method

2.2.1 Sample Preparation

The steel rods were machined to remove the ribs of the rod and other surface irregularities. This was done to ensure that there was no temperature differential across the axis of the rod during heat treatment. The rods were then cut to sample sizes of length 50mm for heat treatment.

2.2.2. Heat Treatment

The steel specimens were austenitised in a furnace at 920°C for one hour and then quenched in water. This was to ensure a diffusionless transformation of the microstructure for the purpose of obtaining a martensite microstructure. The quenched specimens containing martensiteic microstructure were placed in the furnace and heated to a temperature of 700°C and held for 1hr.

2.2.3. Prestraining

Two specimens were tested to fracture, in order to get the tensile properties of the unstrained specimen and identify possible prestrain levels between the Yield Strength and the Ultimate Tensile Strength. This was found to be 7%, 9%, 13% and 20%, hence the other specimens were then separated into four batches of 10 specimens each and marked W, X, Y, Z. Batch W was strained to 7%, Batch X was strained to 9%, Batch Y was strained to 13% and Batch Z was strained to 20%.

2.2.4. Microstructural Analysis

Specimens of the unstrained and two specimens from each of the different prestrain levels were subjected to microstructural analysis by metallography technique and then examined by an optical microscope. These specimens analyzed were prepared by sectioning and mounting, grinding, polishing and etching of the surface.

a. Sectioning

The specimens examined were first sectioned at the midpoint and then mounted on a holder.

b. Grinding

This operation was done to produce 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, i.e. from coarse grade to fine grade. The grinding process was done under running water to wash away the grits and also to avoid overheating. The samples were rotated through 90^0 while changing from one grit size to another. This is to neutralize the scratching effect of the previous grinding of the former grit size.

c. Polishing

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

d. Etching

This was done to reveal the microstructure of the material by removing the layer of the polished surface. The mirror-like surface was etched in 2% nital. Again, it was washed with water, dried and later viewed under the metallurgical microscope.

e. Microscopic Examination

An optical metallurgical microscope with a 400-pixel magnification and fitted with a photographic device was used to view and record the etched surface. The etchant used ensured that the carbides appeared as darkened portions. The results can be seen in plates 1 – 5.

3. Results and Discussion

3.1 Results

The chemical composition of the steel substrate as presented in the Table 1 reveals that the material is a low carbon steel as the carbon in this material is between 0.002-0.25%, while the others are alloying elements present in this material, as steel is basically an alloy of iron and carbon, and other alloying elements [1].

Table. 1. Chemical composition of the steel.

Elements	C	Si	Mn	S	P	Cr	Cu	Ni	Ti	Fe
Composition	0.14	0.18	0.69	0.05	0.03	0.09	0.13	0.06	0.02	98.6

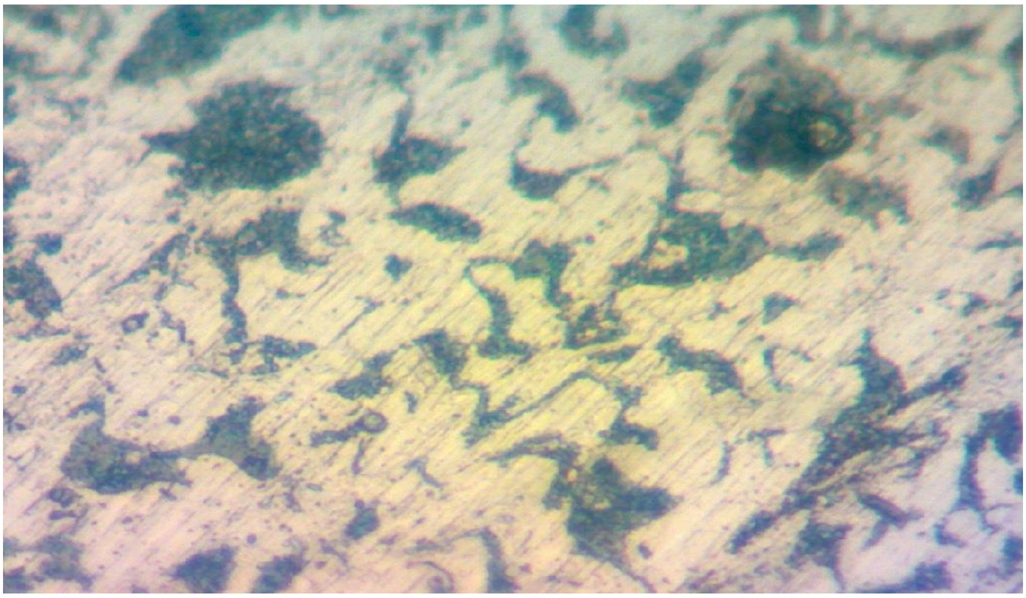

Plate 1: Micrograph of Low Carbon Steel Specimen (unstrained)

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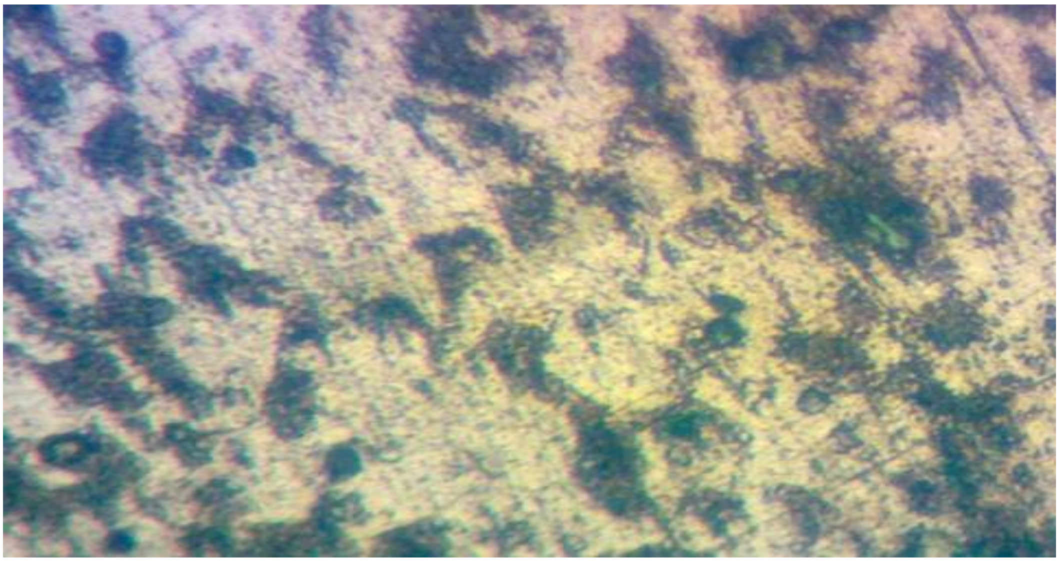

Plate: 2. Micrograph of Low Carbon Steel Specimen (7% prestrained)

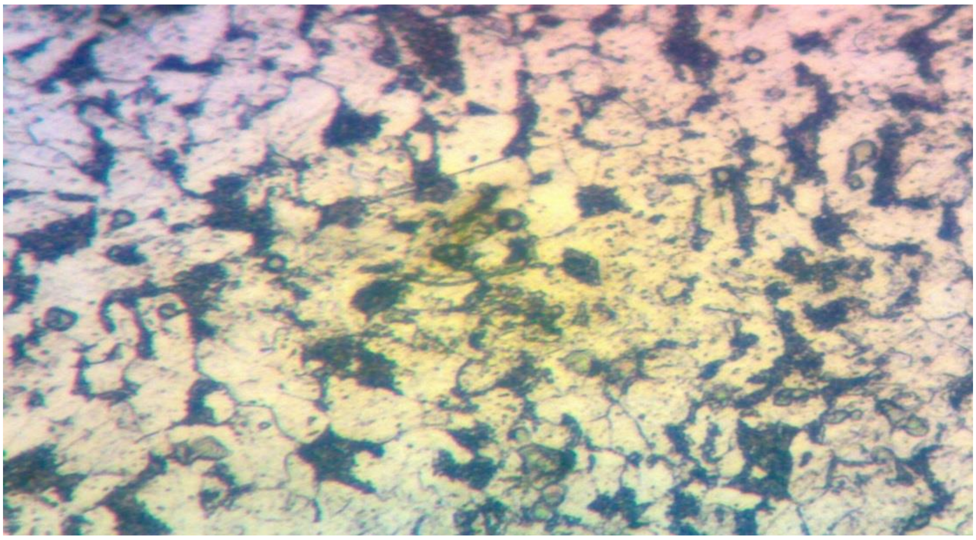

Plate 3.: Micrograph of Low Carbon Steel Specimen (9% Prestrained)

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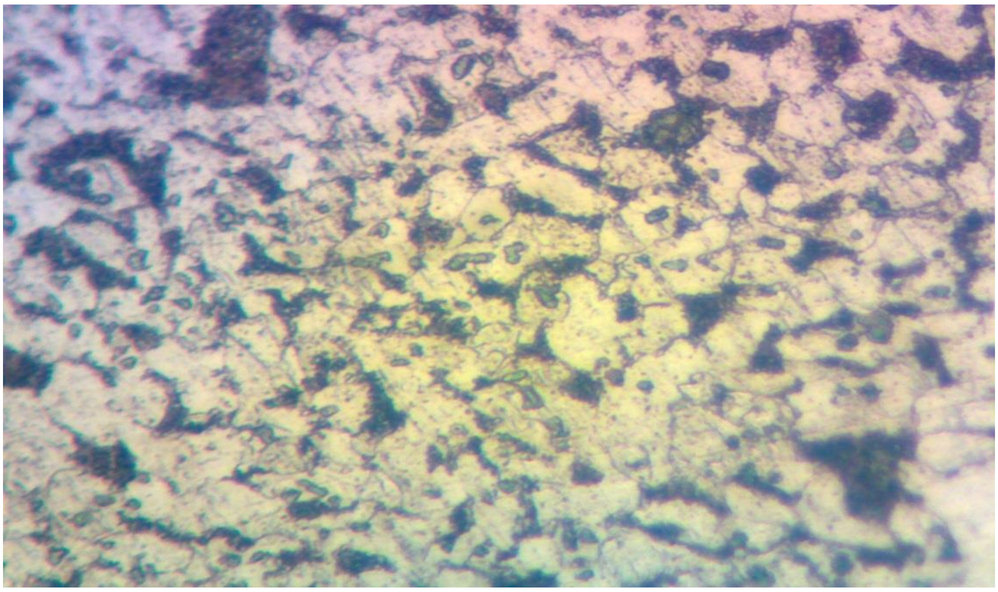

Plate 4: Micrograph of Low Carbon Steel Specimen (13% Prestrained)

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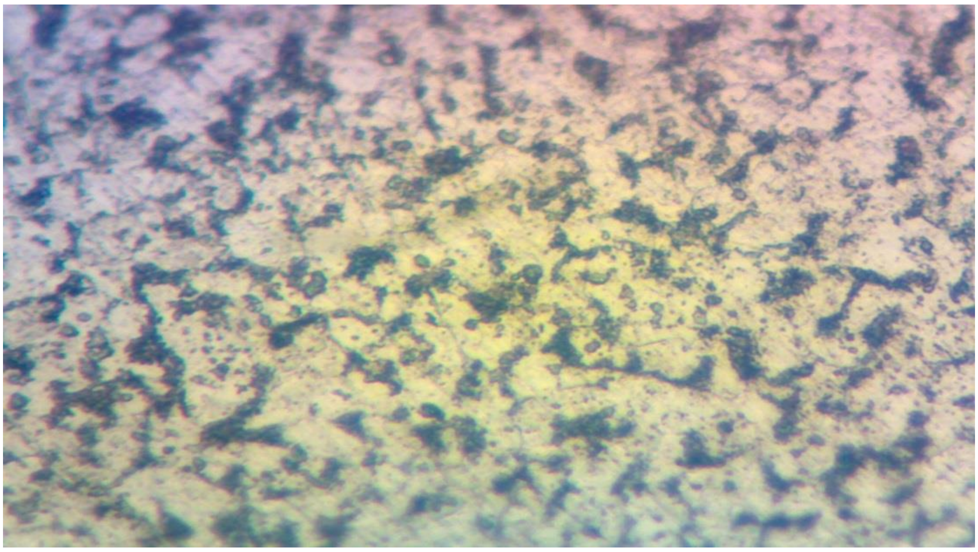

Plate 5: Micrograph of Low Carbon Steel Specimen (20% Prestraine)

3.2 Discussion

The micrographs of the unstrained and pre-strained specimens are shown in Plates 1 – 5. The visible features are the parent ferrite and carbide (darkened). From Plate 1 which is the unstrained specimen shows dispersion of coarse precipitate particles within the ferrite matrix, this also reveals large inter particle distance between the particles. The agglomeration of the precipitate into coarse forms can be attributed to the sufficient thermal energy available when the specimen was reheated after quenching and held, this is supported by [1] which stated that high temperature transformations results in coarse microstructures. As the strain level increases the particles size tend to reduce and are more finely dispersed within the ferrite matrix and also results in a reduction in the inter particle distance. Plate 2 shows the distortion of precipitate particle shape and size resulting from the prestrain, Plate 3 shows a mix of coarse and fine precipitate particles dispersed within the ferrite matrix, it also shows a reduction in the inter particle distance, Plate 4 shows a fine dispersion of precipitate particles with very few coarse particles, the inter particle distance is small and Plate 5 which has the highest prestrain value also shows the finest dispersion of particles. Microstructural changes in prestrained low carbon steel can also be attributed to an increase in dislocation density and formation of sub cell structures in the ferrite, this is also supported by [9] who observed a formation of sub cells and increase in dislocation density due to prestrain. The finer carbide particles formed help to increase the strength of the steel by forming more obstacles to the movement of dislocations. The strengthening is due to the difficulty of the dislocations either shearing or bypassing the particles, this relationship was first showed by Orowon as stated by [1]. Also, the migration of solute atoms to dislocations results in the reduction of the strain energy associated with a give dislocation, therefore when dislocations slip the strain energy of the crystal increases because the solute atoms do not move with the dislocations. The energy comes from the forces acting on the dislocation resulting in an increase in the stress to be applied and the particle can be said to have had a dislocation pinning effect in agreement with [8], who stated that the migration of solute atoms to dislocation sites brings about a dislocation pining effect. With this increase in strength also comes a reduction in the ductility due to the decrease in the mean free path of dislocations.

4. Conclusion

The results show that prestrain has an effect on the microstructure of low carbon steel. The coarse carbide particles become finer as the prestrain value increases and results in a reduction of the inter particle distance. The micrograph of the unstrained shows a dispersion of coarse precipitate particles within the ferrite matrix, this also reveals large inter particle distance between the particles. The micrograph of the 7% prestrain shows the distortion of precipitate particle shape and size resulting from the prestrain. The micrograph of the 9% prestrain shows a mix of coarse and fine precipitate particles dispersed within the ferrite matrix, it also shows a reduction in the inter particle distance. The micrograph of the 13% prestrain shows a fine dispersion of precipitate particles with very few coarse particles, the inter particle distance is small and the micrograph of the 20% prestrain shows very fine precipitate particles finely dispersed within the ferrite matrix.

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