ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, *Vol 9(33), DOI: 10.17485/ijst/2016/v9i33/93526, September 2016* ISSN (Online) : 0974-5645

Study on Dual-Phase Structure of AISI4140 Steel

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Abstract

Heat treatment is a combination of heating and cooling operations, implemented to a metal or alloys in solid state that will produce desired properties. All basic heat treating processes for steel involve the complete or partial transformation or decomposition of austenite. The nature and appearance of these transformation products determine the physical and mechanical properties of given steel. The present work intended to produce a dual-phase structure in medium carbon low alloy Steel (AISI4140) and experimentally investigating the effects of pretreatments (annealing, normalizing) on austenitisation and hence dual-phase properties of AISI4140 steel. Experimental investigation shows considerable positive effect of initial room temperature structure on the characterization of the heat treated dual phase steel. Annealed dual-phase steel has more hardness as compared to normalized dual-phase steel. The dual-phase steel (ferrite-bainite) formed with normalizing as pretreatment has got better impact resistance.

Keywords: AISI4140, Annealing, Dual-Phase (Ferrite-Bainite), Normalizing

1. Introduction

Engineering properties are modified by heat treatment processes so that structural components are able to withstand specified operating conditions and have desired useful life. Heat treatment is the heating and cooling of metals in the solid state to alter the properties. Heat treatment could be said to be a method for strengthening materials but could also be used to change some mechanical properties such as improving formability, machinability, etc.[1–4]

The comparative study is required to predict the level of improvement in properties by dual-phase structure over conventional normalized or as-cast structure and examine its respective effects on the physical and mechanical properties as per the end use.

The term dual phase steels or DP steels, refers to a class of high strength steels which is composed of two phases; normally a ferrite matrix and a dispersed second phase of martensite, retained austenite and/or bainite.

It means dual-phase steels usually contain some volume fractions of high-strength phase such as martensite or bainite, within a softer matrix, ferrite[5]. The ferrite matrix provides the ductility while the discrete bainite phase provides strength. Besides these properties, other useful properties of these steels are low yield strength, continuous yielding behavior, and highly uniform total elongation[6,7]. Mechanical properties of dual phase steels are affected by several factors, including; the volume fraction, the morphology of hard phase[8] and the ferrite grain size.

2. Materials Used

2.1 AISI4140 Steel (EN19)

AISI4140 is medium carbon chromium - molybdenum steel used for a wide range of applications in most industry sectors because of its low cost, good forge ability and machinability. Typical applications are: bearings, bushes, gears, conveyor rolls, hydraulic shafts, nuts and rings. This steel grade responds readily to heat treatment and is comparatively easy to machine in the heat treated condition. The chemical compositions of the steel used in this work are listed in the Table 1.

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Table 1. Composition of AISI4140 steel

Chemical Composition	Weight Percentage
Carbon	0.41
Manganese	0.52
Chromium	1.2
Molybdenum	0.4
Silicon	0.13
Phosphorous	0.02
Sulphur	0.03

2. Experimental Details

The respective test samples are prepared from 16 mm diameter of the as-bought bar. Each test is conducted by four trials in every condition and the average of best three consistent readings is recorded as hardness, strength or impact resistance value. The tests performed are Charpy, Tensile, Hardness and microstructure.

3.1 Specimen Preparation

- Tensile Test Specimen

Figure 1. Tensile test specimen (All dimensions in mm).

CNC code is written for the given shape shown in the Figure 1 and specimens are made on CNC turning center. A rod of diameter 16 mm is clamped into the chuck of the CNC and 86 mm length of the rod is protruded from the chuck. The operating parameters are defined and the machine is started to carry out the machining operation and finished specimens are prepared as per the requirement and is shown in Figure 2.

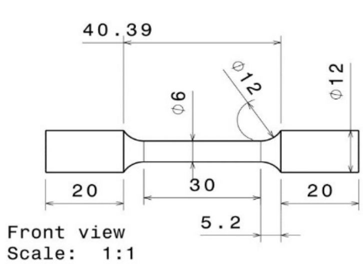

Figure 2. Prepared tensile test specimen.

- Charpy Test Specimen

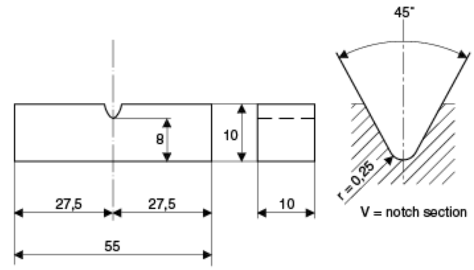

Figure 3. Charpy test specimen (All dimensions in mm).

The standard Charpy Impact Test specimen consists of a square bar of metal (55 x 10 x 10 mm) having a notch machined across one of the larger dimensions.

Notch Specifications:

- Type of notch: V
- Depth: 2 mm
- Notch Angle: 45°
- Radius of the Notch Base: 0.25 mm

The as-bought steel rods of diameter 16 mm have been reduced to 14.2 mm diameter and 55 mm long using conventional lathe.

Then the reduced steel rods were made into square bars of 55 x 10 x 10 mm using VMC (Vertical Milling Machine).

After machining on VMC, the Filing tool has been used to remove the burrs on the bars.

After the square bars were made, the V-notch has been made on the bars using the shaping machine (shaper). For this purpose a special tool of tool angle 45° is used. Figures 3 and 4 show the shape and size of standard Charpy test specimen and prepared specimens respectively.

Figure 4. Prepared impact test specimen.

- Hardness Test Specimen

As per the standard, the cylindrical specimen 20 mm diameters, 15 mm length are prepared by turning and cutting by bands saw. For micro structure analysis the cylindrical specimen is rubbed with different grades of emery papers i.e. 400, 600, 1000 and 2000 grit size in series to get fine surface finish. Finally fine polishing to mirror finish is performed using disc polisher embedded with velvet cloth and diamond polishing abrasive.

Both the Microstructure and Hardness tests can be carried out on same specimen, each test on either side.

Figure 5 shows the shape of the specimen used for hardness and microstructure analysis.

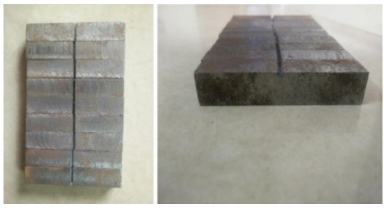

Figure 5. Prepared hardness and microstructure test specimen.

3.2 Heat Treatment

Five batches are made with each batch having four each for tensile test, Charpy test and one for hardness and microstructure analysis.

First batch is tested for as bought (annealed) condition.

Second batch of specimen is austenitized in intercritical temperature of 790°C and held isothermally for 2h. and then quenched in a salt bath of sodium nitrate and sodium nitrite (1:1) at 300°C for 8min. and 20s. to form lower bainite dual-phase structure of ferrite and bainite.

Third batch is austenitized similarly but quenched in same salt bath maintained at 400°C to form upper bainite dual-phase structure of ferrite and bainite.

Fourth and fifth batches are first normalized by isothermal heating at a temperature of 900° for 2h. and then air cooling, followed by converting into lower and upper bainites as previous steps for dual-phase structure of ferrite and bainite.

3.3 Tests

- Tensile Test

The tension test is done by applying a gradually increasing uniaxial load (static load). This is also called static tension test.

This test is performed on the universal fatigue testing machine which has a provision to conduct either tension-tension or tension compression type fatigue test. The machine can produce maximum of 50KN and a displacement of 166mm.The main component of the machine is a hydraulic actuator which is driven by hydraulic power pack under a pressure of 220 bar.

- Charpy Test

Charpy test consists of breaking a 'V' notched standard test piece, gripped supported at the ends, by one blow from a swinging hammer of striking energy of 300N-m. Impact value is the energy absorbed by the specimen for fracture expressed in N-m.

- Hardness Test

Rockwell hardness is a based on the degree of indentation on the test piece by action of an indenter under a given static load, various loads and indenters are used depending on the condition of the test.

The test is conducted in a specially designed machine that applies load through a system of weights and levers. The indenter may be either a steel ball (1/16"diameter) or a conical diamond (120 degrees apex angle) with a slightly rounded point called a `brale'.

The hardness number can be read directly from a graduated dial gauge. The dial has two sets of markings, one red and the other black.

The outer set marked in black is the 'c' scale and the inner red is the 'B' scale both have 100 divisions but differ from each other by 30 hardness numbers. 'B' scale is used with ball indenter and 'C' scale with diamond cone and 'C'is for steels.

- Microstructure Test

Metallography consists of the microscopic study of the structural characteristics of the metal or alloy. This helps to determine grain structure that includes the size, shape and distribution of various phases. This can be used to determine the effects of various phases obtained by different thermal treatment on the mechanical properties[8].

4. Results and Discussions

4.1 Tensile Test Results

Figures 6 to 10 tensile stress versus strain of as-bought, annealed lower bainite, annealed upper bainite, normalized lower bainite, normalized lower bainite respectively. The ultimate tensile strength of the respective conditions are shown in the form of bar chart as shown in Figure 11. As it can be seen from the above comparison, annealed lower bainite dual-phase steel has highest ultimate tensile strength and as bought (annealed) steel has lowest ultimate tensile strength.

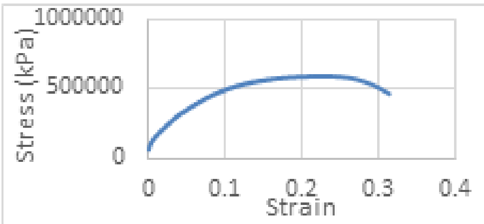

Figure 6. Stress vs Strain for As Bought Specimen.

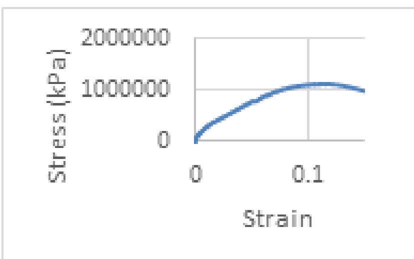

Figure 7. Stress vs Strain for Annealed Lower Bainitic Dual-Phase Steel Specimen.

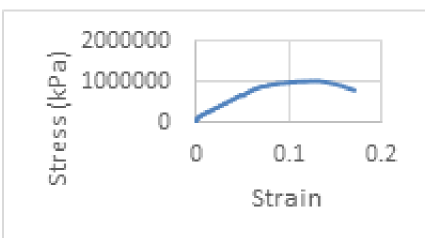

Figure 8. Stress vs Strain for Annealed Upper Bainitic Dual-Phase Steel Specimen.

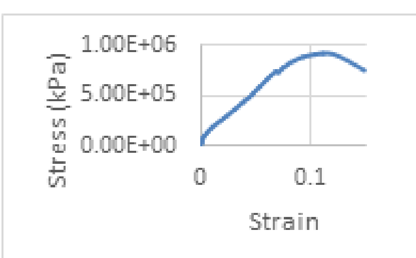

Figure 9. Stress vs strain for normalized lower bainitic dual-phase steel specimen.

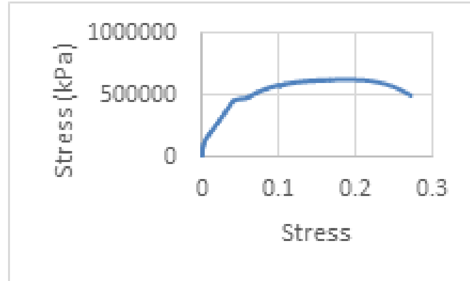

Figure 10. Stress vs. strain for normalized upper bainitic dual-phase steel specimen.

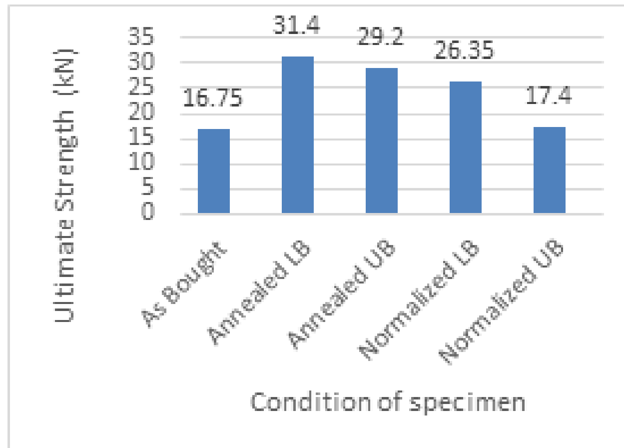

Figure 11. Ultimate strength as a function of type of treatment on the specimen.

It is also observed that lower bainite dual-phase has higher ultimate tensile strength than the upper bainite dual-phase steels. Also, an annealed dual-phase steel has higher tensile strength than normalized dual-phase steels. The strength is also the function of fineness of the grain[9]. Since lower bainite has finer ferrite and carbide phases than that of upper bainite, shows better ultimate tensile strength. Annealed and subjected to dual phase treatment has got higher tensile strength may be due to undissolved alloy carbides during austenitising.

4.2 Charpy Test Results

Figure 12 shows the different heat treatment impact result and comparison, as bought (annealed) steel has lowest toughness and normalized upper bainite dual-phase has highest impact resistance. It is also observed that lower bainite dual-phase has lower impact resistance than the upper bainite dual-phase steels irrespective of initial grain size. Also, an annealed dual-phase steel has lower impact resistance than normalized dual-phase steels. In all the cases upper bainite has got higher toughness than the lower bainite. The lower toughness value in the case of lower bainite may be due to the formation of some amount of brittle martensite phase during isothermal formation of bainite.

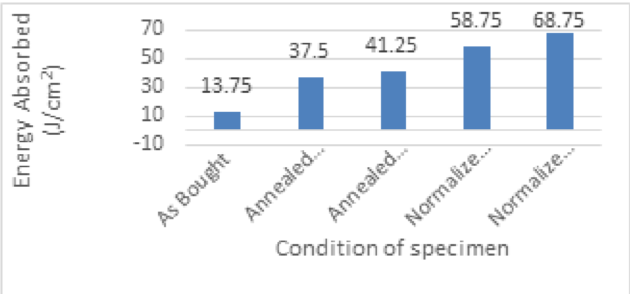

Figure 12. Impact strength as a function of type of treatment on the specimen.

4.3 Hardness Test Results

From the Figure 13 shows the different heat treatment hardness values, Annealed upper bainite shows excellent hardness compared to other conditions. There may be undissolved carbides present during austenitising. It may be also due to the precipitation of more amount of Chromium and Molybdenum carbides due to the longer soaking time. In the case of normalized upper bainite least hardness is noticed. It may be due to the absence of undissolved carbides during heating to normalizing range.

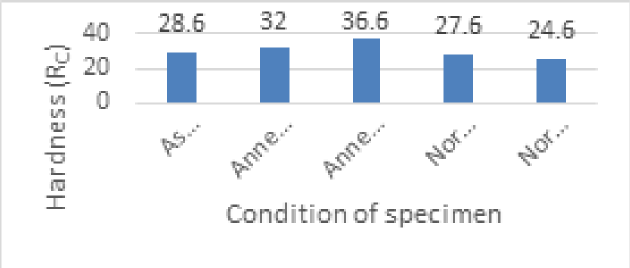

Figure 13. Hardness as a function of type of treatment on the specimen.

4.4 Microstructure Test Results

Figures 14 to 18 shows the microstructures of as bought steel and dual phase steels obtained in different conditions. Microstructure of as bought steel shows proeutectoid phases embedded in pearlite matrix. Normalised lower bainite shows lath bainitic structure similar to martensite with least proeutectoid phases as compared to annealed lower bainite, which has got more number of coarser proeutectoid phases (undissolved carbides). Similarly normalised upper bainite shows bainitic structure similar to pearlite with least proeutectoid phases as compared to annealed upper bainite, which has got more number of coarser harder proeutectoid phases (undissolved carbides) embedded in coarser pearlite type of bainite.

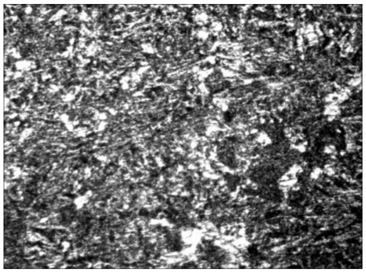

Figure 14. Microstructure of as bought steel (500X).

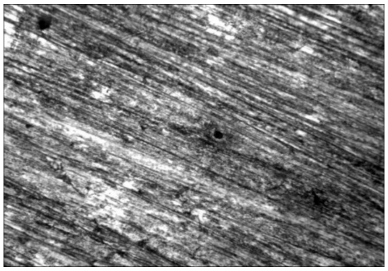

Figure 15. Microstructure of annealed lower bainite dual-phase steel (500X).

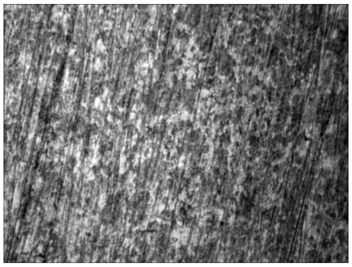

Figure 16. Microstructure of normalized upper bainite dual-phase steel (500X).

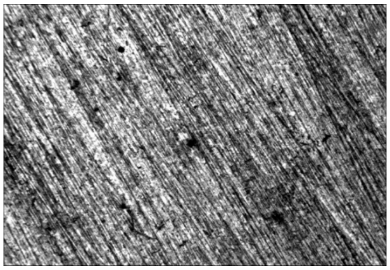

Figure 17. Microstructure of normalized lower bainite dual-phase steel (500X).

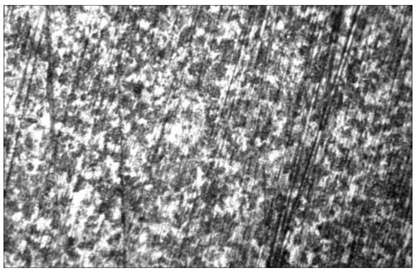

Figure 18. Microstructure of annealed upper bainite dual-phase steel (500X).

5. Conclusions

The AISI4140 steel is heat treated efficiently for different bainitic structures by changing the initial room temperature structure (annealing or normalizing). It has found that initial room temperature structure has got considerable effect on the characterization of the heat treated steel. However, the following conclusions are arrived from the experimental work.

- Annealed lower bainite dual-phase steel has highest ultimate tensile strength and as bought (annealed) steel has lowest ultimate tensile strength.
- It is also observed that lower bainite dual-phase has lower impact resistance than the upper bainite dual-phase steels irrespective of initial grain size (annealed or normalized).
- Annealed dual-phase steels have lower impact resistance than normalized dual-phase steels.
- In all the cases upper bainite has got higher toughness than the lower bainite.
- Annealed upper bainite shows excellent hardness compared to other conditions.
- Microstructure of as bought steel shows proeutectoid phases embedded in pearlite matrix.
- Normalised lower bainite shows lath bainitic structure similar to martensite with least proeutectoid phases as compared to annealed lower bainite, which has got more number of coarser proeutectoid phases (undissolved carbides).
- Normalised upper bainite shows structure similar to pearlite with least proeutectoid phases as compared to annealed upper bainite, which has got more number of coarser harder proeutectoid phases (undissolved carbides) embedded in coarser pearlite type of bainite.

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