Results in Engineering 4 (2019) 100044

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.editorialmanager.com/rineng/Default.aspx

Microstructural assessment of AISI 1021 steel under rapid cyclic heat treatment process

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ARTICLE INFO

Keywords:
Mechanical properties
Collapsed building
Steel rods
Chemical compositions
Percentage elongation

ABSTRACT

This research was aimed at using image analysis to describe the effects of rapid cyclic heating on mild steel. AISI 1021 steel sample used in this study was subjected to quenching heat treatment followed by 1, 2, 3, and 4-cycles of rapid heat treatment. The as-treated steel samples were characterized by Brinell hardness tests, Charpy V-notch impact tests, optical microscopy, and image analysis using Image J software. The results revealed that the grain size decreased from 1.07 μm in the control sample to 0.79 μm in the third cycle sample and increased to 0.86 μm in the fourth cycle sample. However, the results revealed that two-cycles of rapid heat treatment was enough to produce ultra-fine grains and impact ductility in mild carbon steel.

Introduction

Heat treating of steel requires a combination of timed heating and cooling operations. This process is to incorporate better desirable properties into the material, thereby improving the microstructure of the material [1]. Several studies have been done on the rapid heat treatment of steel with quenching [2,3]. One or two-cycles of rapid heat treatment has been reported to produce ultra-fine grain hence increasing the strength and toughness in mild steel [4]. However, further findings appear inconclusive and the thrust to explore on this claim. More so, the effects of rapid cyclic heat treatment on mild steel are required to be critically examined. Therefore, this study was aimed at ascertaining the effects of rapid cyclic heat treatment on the mechanical properties and microstructure of AISI 1021 steel using image J analysis software.

Methods

AISI 1021 steel sample was obtained in a local market in Ilorin, Nigeria. The steel sample was characterized to obtain the elemental compositions (See Table 1) using an optical electron spectrometer. The samples were cut and machined to the dimensions of the required test with the aid of lathe machine. The samples were then labelled for the various cycles of heat treatment. The control

Table 1
Chemical composition (wt. %) of the steel sample.

C	Si	S	P	Mn	Ni	Al	W
0.213	0.252	0.030	0.028	0.779	0.131	0.292	<0.0001
Cr	Mo	V	Cu	Nb	B	Ti	Fe
0.138	0.020	0.030	0.336	0.014	0.001	0.009	97.700

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https://doi.org/10.1016/j.rineng.2019.100044
Received 17 May 2019; Received in revised form 25 September 2019; Accepted 29 September 2019

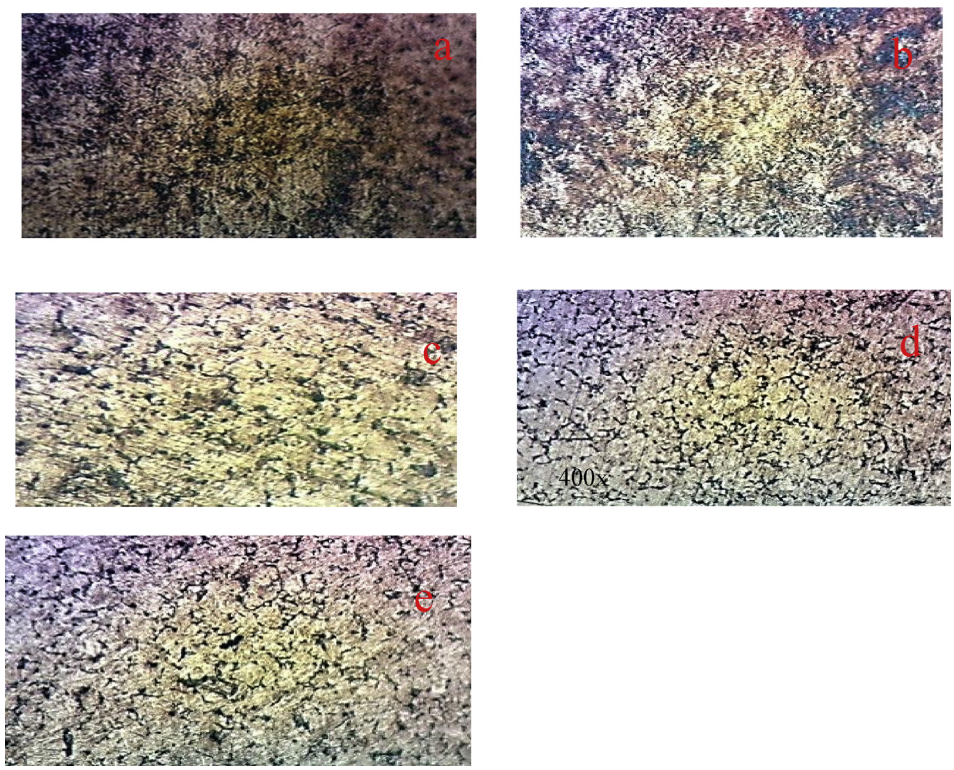

Fig. 1. Microstructure at 400x magnification (a) control (b) one cycle (c) two cycles (d) three cycles (e) four cycles.

sample was subjected to diffusional heating and quenching. All samples were subjected to diffusional heat treatment from room temperature to austenite (852 °C) and were soaked for 10 mins [3]. The austenitic heat-treated steel samples were rapidly cooled in water.

Each cycle of rapid heat treatment requires fast heating (heating rate of above 20 °C/min) to austenitic temperature and fast cooling (quenching) to room temperature. This process was achieved by charging the samples into an electric resistance furnace, preheated to 900 °C for 10 mins, and then quenching in water. The samples were exposed to 1, 2, 3, and 4-cycles of rapid heat treatment. These samples were prepared for metallographic examination using an accuscope optical microscope (Serial No. 0524011) and were further analyzed with Image J analysis (version K 1.45) software [5]. Mechanical tests were also carried out on the samples to determine their hardness number, impact energy and energy absorbed, yield strength, ultimate tensile strength, and young modulus.

Results

The chemical compositions of the AISI 1021 steel sample are displayed in Table 1. The microstructures of the samples are shown in Fig. 1. The phase formed in the microstructure by quenching was martensite (Fig. 1a) with a mottled contrast. Further cycles of rapid heat treatment lead to the production of refined martensite with smaller grain size. Further cycles of rapid heat treatment lead to the production of refined martensite with smaller grain sizes. The image analysis parameters were determined. More so, the microstructure area parameters for area plotting were obtained. These parameters were used to graphically represent the number of pixels in the image, with the intensity values. The pink colour depicts the distribution of the carbide particles in the iron matrix (blue and green colorations), as shown in Fig. 2. The carbide particles are more evenly distributed in the iron matrix in the two-cycles sample (Fig. 2c). Furthermore, the least value of Young's modulus obtained for the two-cycles sample depicts it as the most ductile (Table 2). Hence, two-cycles of rapid heat treatment could be

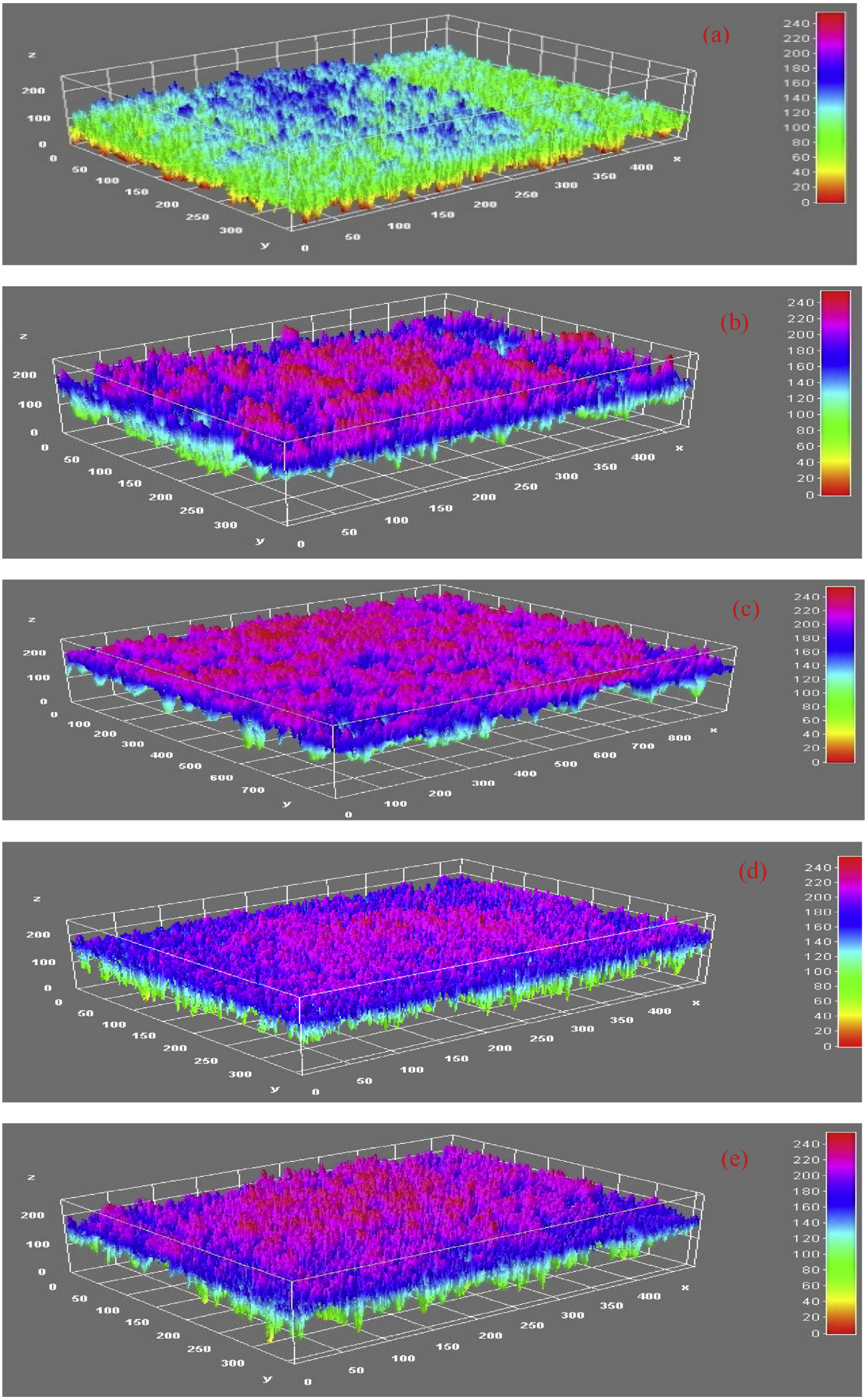

Fig. 2. Surface plot (3D view) of microstructures (a) control (b) one cycle (c) two cycles (d) three cycles (e) four cycles.

Table 2
Mechanical properties and grain size of samples.

Samples	YM (N/mm^2)	UTS (N/mm^2)	BHN	IE (Joules)	EA (N.m)	Grain Size (μm)
Control	22652.22	1247.78	271.00	46.80	230.98	1.09
1-Cycle	16398.50	1027.45	284.00	51.20	296.17	1.00
2-Cycles	15356.30	833.38	323.00	55.40	235.15	0.81
3-Cycles	20616.00	1112.24	377.70	61.50	265.99	0.79
4-Cycles	27768.60	1321.78	562.70	64.60	253.65	0.86

*YM-Young Modulus, UTS - Ultimate Tensile Strength, BHN - Brinell hardness number, IE-Impact Energy, EA- Energy Absorbed.

affirmed to be sufficient to impart ductility in mild steel.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Acknowledgements

The authors appreciate the assistance rendered by Materials and Metallurgical laboratory of Obafemi Awolowo University, Ile Ife and University of Ilorin, Nigeria. Also, our appreciation goes to the management of Landmark University, Omu-Aran for sponsoring the publication of this study.

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