Archives of Materials Science and Engineering

Volume 129
Issue 1
September 2024
Pages 17-23

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

DOI: 10.5604/01.3001.0054.9063

Effect of carburising treatment parameters on low carbon steel properties for vehicle structures

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ABSTRACT

Purpose: The purpose of conducting this research is to improve the mechanical properties of low-carbon steel for use in various industrial applications at a lower cost than titanium and high-entropy alloys.

Design/methodology/approach: We can achieve the goals by performing carburising processes at different depths that depend on the heat treatment conditions.

Findings: The results showed a significant improvement in tensile strength (23, 126, 146 MPa), surface hardness (134, 516, 246 MPa), and a decrease in elongation (60, 91, 88%); in slow cooling in the furnace, water quenching, water quenching with annealing in succession where the mechanical properties are controlled by controlling the refining and heat treatment conditions to control the microstructure and desired properties that achieve the best steel surface.

The importance of improvements in tensile strength, hardness, and elongation for industrial applications is the ability to withstand work in complex industrial conditions based on the amount of applied forces and high temperatures.

Research limitations/implications: We suggest carrying out the carburising processes at greater depth and controlling the quenching process to achieve better mechanical properties.

Originality/value: The effect of carburizing at different depths on low-carbon stainless steel was studied at different annealing conditions by controlling the cooling rate. The results showed a significant increase in tensile strength, especially for samples that were carbonised and quenched in water, as the best results in tensile strength, hardness, and elongation were for samples quenched in water.

Keywords: Low carbon steel, Carburizing, Tensile strength, Hardness, Microstructure

Reference to this paper should be given in the following way:

N.K.F. Al-Asadi, M. Ali, A.K. Hassan, Effect of carburising treatment parameters on low carbon steel properties for vehicle structures, Archives of Materials Science and Engineering 129/1 (2024) 17-23. DOI: https://doi.org/10.5604/01.3001.0054.9063

PROPERTIES

1. Introduction

Due to the wide uses of carbon steel in many engineering and practical applications [1], unlike other metals, such as copper [2], steel can significantly improve its properties in inexpensive ways to expand the range of its uses in various industries, such as the automobile industry [3], chemical industries [4], medical industries [5], etc. It was necessary to improve the surface properties of carbon steel in order to increase its resistance to friction and wear while maintaining the core, which is tough to give good resistance to impact. Tough and stiff steel can significantly reduce many types of damage during service life, such as vibrations [6-9] and rapid fracture [10]. Many researchers have turned to several methods to improve the properties of carbon steel, whether by using heat treatments [1] or coating processes. Many coating processes range from metallic or polymeric [11] to oxide-based ceramics [12]. Among them, solid carburising processes have additional advantages as they are considered one of the inexpensive methods, easy to apply, and do not require high temperatures to achieve them. [13- 16].

The solid carburising process was carried out by heating the steel with the carburising mixture to the transformation temperature into austenite above the A3, in the range of 900 to 95°C, as shown in Figure 1 [15]. The carbon atoms penetrate the metal, raising the percentage of carbon on the surface to a percentage that may exceed 0.8 %. It depends on the period of carburising and the temperature. The thickness of the carburised depth can be controlled by controlling the two factors above [17].

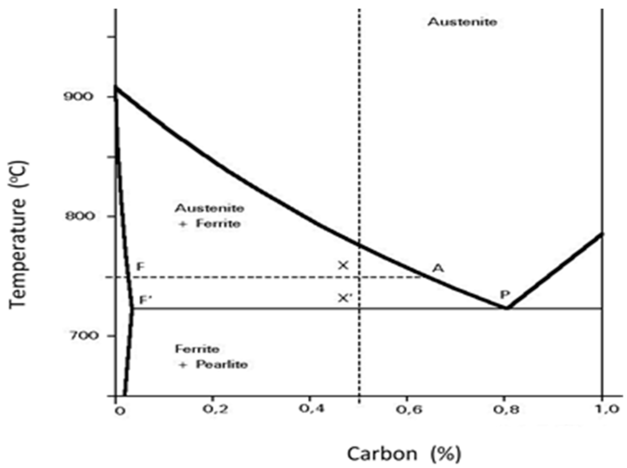


Fig. 1. Carbon - Iron diagram (steel part) [17]

K Palaniradja et al. [18] studied the effect of furnace temperature and quenching time on the surface integrity of the case-hardened components in gas carburising. The results showed that preheating before gas carburising further enhanced the surface hardness and its depth.

According to Shristee Singh [19], the carburising process improves hardness, tensile strength and wear resistance when mild steel is carburised at 860°C with 3 hours of soaking.

P.T. Arasu et al. [20] studies showed that the carburizing process effectively affects the hardness of steel when carburised for 120 minutes at 920°C followed by air cooling. The Vickers hardness increased from 193.7 to 684.5. The reason is the increase in the percentage of carbon on the surface due to austenite formation.

R.R. Panda [21] studied different carburising conditions, and the results showed that the hardness of mild steel increased from 51 to 57 RHC when raising the treatment temperature from 850°C to 950°C for 3 hours. No one has performed this process to improve the mechanical properties of low-carbon steel for use in vehicle industrial applications at a lower cost than titanium and high-entropy alloys.

2. Materials and methods

Low-carbon steel rods were used for sample preparation and the chemical composition, as shown in Table 1.

2.1. Carburising process

Solid carburising was used to prepare the samples. A mixture of carburising was prepared by mixing 70% wood charcoal powder and 30% sodium carbonate Na_2CO_3. In practice, the steel samples were immersed in the carburizing mixture in a tightly sealed steel box and placed inside a temperature-controlled furnace. The box and its contents were heated slowly to a carburization temperature of 910°C, For different periods (0.5, 1, 1.5, 2) h. When the required temperature reaches the desired temperature, the samples are cooled by three methods:

1. Slow cooling inside the furnace;
2. Fast cooling by quenching in water;
3. Fast cooling by quenching in water and annealing at 300°C for one hour.

2.2. Tensile test

The German-made Wolpert-W Lister tensile device was used. The samples used in the test were prepared according to ASTM E8M-13a, as shown in Figure 2.

Table 1.
Chemical composition of low-carbon steel

	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Fe
wt.%	0.21	0.15	0.67	0.03	0.04	0.03	0.003	0.07	0.03	Rem.

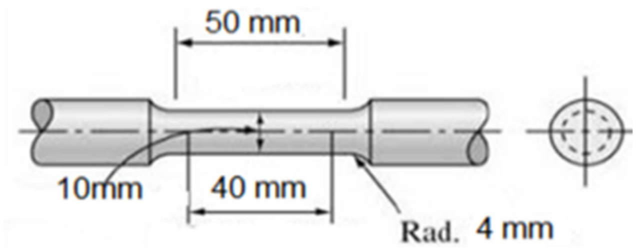


Fig. 2. The tensile test sample

2.3. Hardness test

The hardness was measured before and after the carburising operation for the surface and centre of the sample using a Vickers-type Wolpert, and the weight was applied to it, which was 200 grams. Four readings were taken for each sample and the average. The depth of the carburising layer was measured using the same device after preparing the samples by polishing and Nital solution etch (5% nitric acid + 95% alcohol).

2.4. Microstructure test

Microscopic images were prepared using an optical microscope of Olympus type.

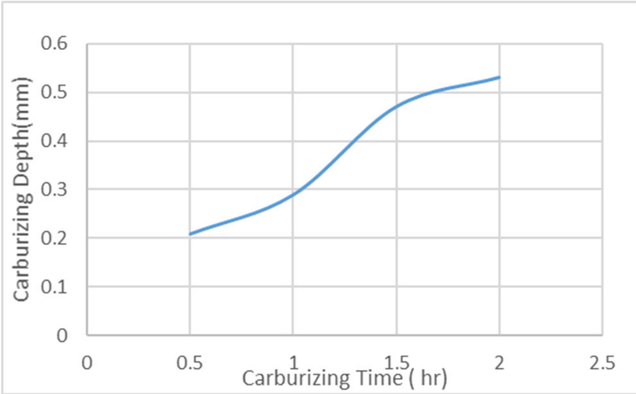
3. Results and discussion

Surface treatment of metal products is very important to increase their resistance to friction and wear, increasing durability. The current study is a simple contribution to one of the commonly used methods for increasing the surface hardness while maintaining the tough core to impact resistance using the carburizing process.

Figure 3 shows the effect of carburising time on the carburized surface area and carbonation depth. The results show an increase in the percentage of surface area and carbonation depth with increasing time. It is a natural result of the long exposure period to high temperatures in the presence of the carbonation mixture. Based on the results above, choosing the appropriate time for this process is possible.

The effect of carburizing on the mechanical properties of low-carbon steel is shown in Figure 4, where it is noted that the tensile strength increases with the increase in the percentage of carburised surface area in order to increase the surface hardness and treat surface defects through this treatment process. The reason can also be attributed to the change in structure from ferrite to pearlite, as shown in Figure 7 b and c. On the other hand, we can notice a decrease in the elongation percentage, and surface hardness increased clearly, with the central hardness almost unchanged, as shown in Figures 4, b and c [22,23].

a)



b)

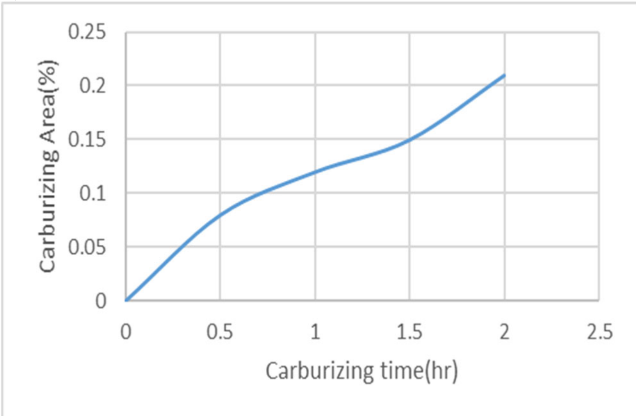
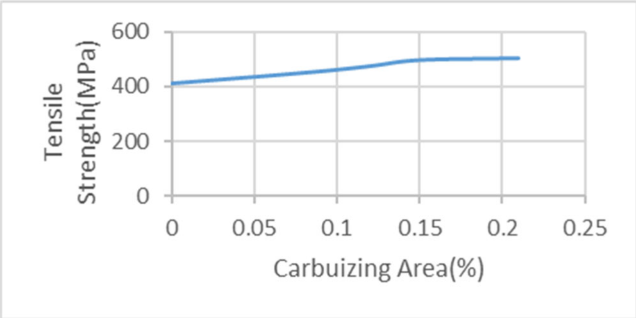


Fig. 3. Effect of carburising time on a) carburizing depth, b) carburising area

Samples rapidly cooled in water after treatment showed a significant increase in tensile strength (Fig. 5a) due to the structure's transformation into martensite, as shown in Figure 7e. The highest tensile strength achieved was 930 MPa. As seen from Figure 5c shows a clear increase in the hardness, reaching 765 on the surface, corresponding to a slight increase in the hardness in the centre, reaching 487. It is accompanied by a clear decrease in elongation (Fig. 5b). The lowest elongation was achieved when carburising for 2 hours, amounting to 3 mm. It is due to the transformation of austenite into hard martensitic. It is consistent with previous research that demonstrated an increase in austenite volume by 1% after the carburising process [24-28].

a)



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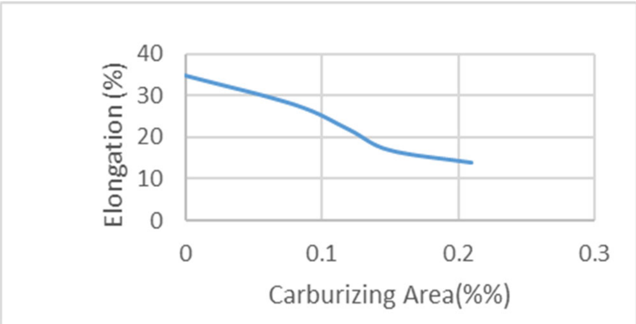


c)

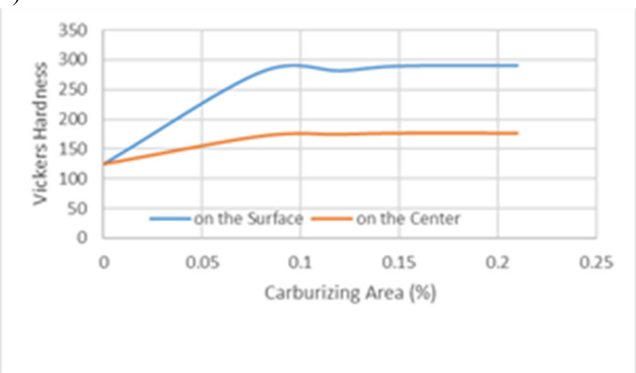
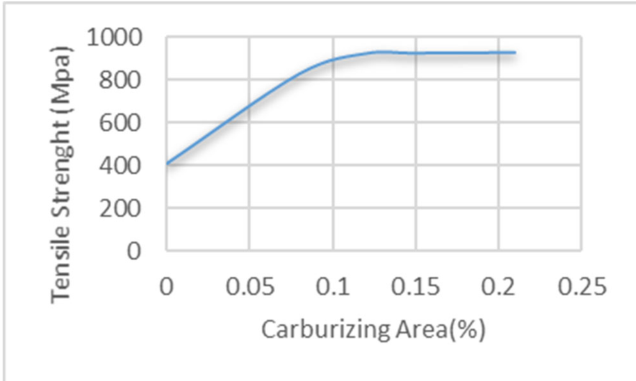


Fig. 4. Effect of the carburising area on: a) tensile strength, b) elongation, c) hardness (slow cooling inside the furnace)

Figure 6 shows the effect of carburising area on mechanical properties with samples quenching in water and annealing at 300°C for one hour. An increase in tensile strength up to 1010 MPa. From the results, a slight change in the tensile strength value is observed with the change in the carburising time due to the effect of the annealing process, which did not lead to a radical change in the microstructure. Still, the increase in the tensile strength results from removing thermal and internal stresses. It is accompanied by a decrease in elongation and an increase in hardness, but the effect of carburising time on the amount of the values is small.

a)



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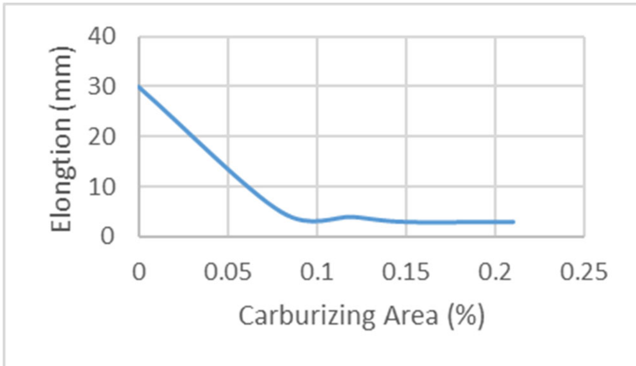

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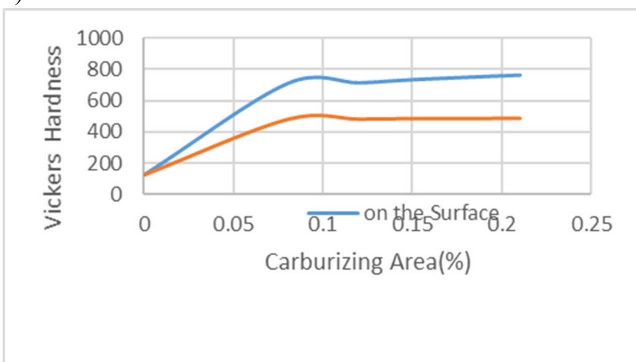
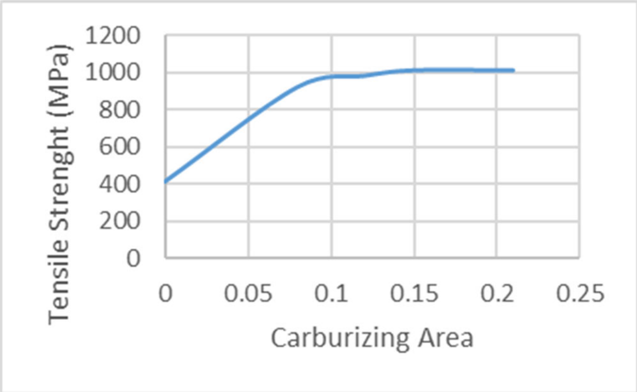
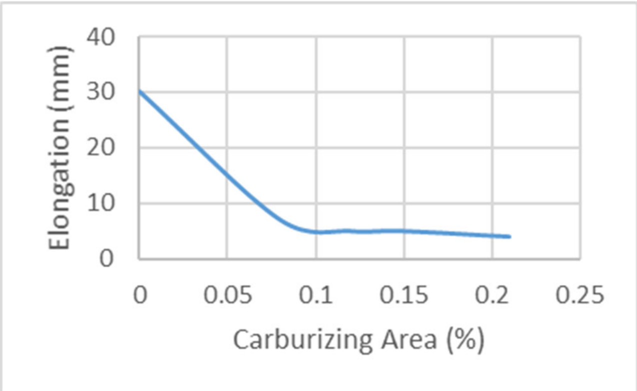


Fig. 5. Effect of the carburising area on a) tensile strength, b) elongation, c) hardness (fast cooling by quenching in water)

a)



b)



c)

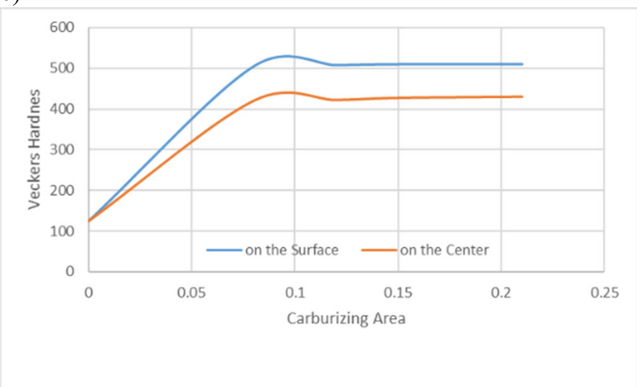


Fig. 6. Effect of the carburising area on a) tensile strength, b) elongation, c) hardness (fast cooling by quenching in water and annealing at 300°C for one hour)

4. Conclusions

The surface properties of steel can be improved by controlling the time and temperature of carburising and the carburising mixture. The results showed a noticeable improvement in the tensile strength (23, 126 and 146 MPa), surface hardness (134, 516, and 246 MPa), and decrease in elongation (60, 91, and 88%) when (slow cooling in a furnace, water quenching, and water quenching with annealing respectively). Mechanical properties must be controlled by controlling the carburizing conditions and heat treatment to control the microstructure and the required properties that achieve the best surface for the steel.

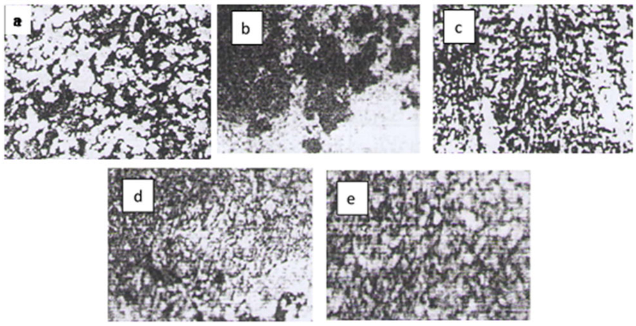


Fig. 7. Microstructure of low carbon steel: (a) without treatment (b) 1 hr. treatment and slow cooling in furnace 40X (c) 2 hr. treatment and slow cooling in furnace 40X (d) water quenching 400X(e) water quenching and annealing 400X

Research funding

This research received no external funding.

Authors contribution

Nibras Kamil Falyyih Al-Asadi: Experimental work, Writing – original draft. Muslim Ali: Conceptualization, Methodology, and Investigation. Ahmed K. Hassan: Reviewing and Editing.

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