Paper ID: MS-20

An Investigation of Microstructure and Micro-hardness in Carburized Steels to be Used for Manufacturing of Heavy Duty Transmission Gears/Shaft

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Abstract

Carburizing treatment is widely used for surface hardening of steels, which provides the combination of hard surface and soft interior. The treatment is used for the devices which involve extensive wear during operation. In this paper, the effect of carburizing on the case depth and the microstructure of steels has been investigated. The effects of annealing, hardening, and tempering on carburized microstructure are studied in a systematic way. A microhardness profile was developed from the experiment which showed how hardness gradually decreased from edge to core. The case depth was measured from both microstructure and microhardness profile and verified with our theoretical value. ImageJ software was used to analyze the microstructure. Here, the surface hardening of steels was designed through pack carburizing. A high percentage of pearlite was found at the outer perimeter of the annealed sample, however, the edge microstructure of hardened and tempered sample showed high carbon martensite.
Keywords: Carburizing, Microstructure, Microhardness.

1. Introduction

Carburizing treatment provides surface hardness with a deeper case depth [1]. Carburizing is the addition of carbon to the surface of the sample through diffusion [3]. Some heat is needed to enhance the diffusion process. The depth of diffusion depends on carburizing time and temperature [6]. After carburizing, in most of the cases, specific treatments are applied to improve hardness. The low and medium carbon steel can be surface hardened without the problem of distortion through surface hardening [2]. Some heat-treatments are required after finishing the carburizing like hardening by quenching or annealing. Any hardened sample should go through tempering treatment to avoid distortion and to release the residual stress [7]. In this investigation, pack carburizing was used which is one of the oldest and a labor-intensive process, though it is widely used for less expenses. Annealing was performed for recrystallization [9]. The average grain size increases with annealing treatment. However, during quenching, sharp needle-like martensite forms in microstructure which causes increased hardness. Moreover, tempering causes tempered martensite formation [8] which has a relatively blunt edge and small length than martensite. Tempering also causes certain hardness to drop.

2. Methodology

Initially, the chemical composition of the sample was measured in optical-electronic spectroscopy (OES). The table 2 shows the initial carbon percentage in the sample. The as-received sample was prepared to examine the initial microstructure. Sample was prepared through emery paper and wheel polishing. Finally etching was done by using acetone and 2% nital.

Carburizing method

The carburizing time was calculated theoretically- based on the sample thickness; we assume the case depth will be 400µm.

$$Case\ Depth = \frac{31.6 * \sqrt{t}}{10^{\frac{6700}{T}}} \tag{1}$$

Here, t = time in Hour, CD= case depth in inch= 400µm=0.015 inch, T =absolute temperature in rankine =2177.91° R. So, holding time, t= 22 min. For considering heat loss and furnace efficiency, the holding time will be 35 min. Upper critical temperature [5] is calculated from this following equation,

$$A3=910\ °C-203\times(\%C)-15.2\times(\%Ni)+44.7\times(\%Si)+100\times(\%V)+31.5\times(\%Mo) \quad (2)$$

From this formula, carburizing temperature was calculated (896.8°C+40°C) or 936.8 °C.
Samples were packed in an environment with high carbon content. The pack carburizing mixer and their amount was given in table 1.The samples were heated inside the muffle furnace with the production of carbon monoxide. Carbon monoxide is a reducing agent which causes the reduction on the steel surface with the release of carbon that is diffused into the surface because of high temperatures. The surface carbon may in the range of 0.7% to 1.2% depending on the process environment [2].

$$CO_2+C= CO$$
$$Fe+ CO= Fe_\gamma C +CO_2$$

Table 1. The pack carburizing mixer and their amount

Carburizing mixer	**Charcoal**	**COKE**	**Sodium carbonate**	**Barium carbonate**	**Calcium carbonate**
Amount(%)	50	30	5	10	5

After heating at 937° degree Celsius for 35 minutes, samples were cooled by furnace cooling. Thus annealed sample was prepared. The others were quickly quenched in ice cold water. Then sample was heated at 160° degree Celsius for 60 minutes. Thus hardened &tempered sample was prepared.

3. Result and discussion

The following chart shows the initial chemical composition of as-received sample.

Table 2. The initial chemical composition of sample.

Fe	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Al**
98.15	.18	.35	.86	.035	.027	.136	.018
Cu	**Ni**	**N**	**B**	**Nb**	**Ti**	**Mo**	**V**
.163	.061	.006	.0009	0	0	0	.0002

From the composition, it was observed that the samples contain low carbon. Therefore, the initial microstructures contained ferrite and pearlite. Initially, two micrographs were collected from the centre and edge portion of the samples. Fig 1 shows initial microstructure of as-received sample.

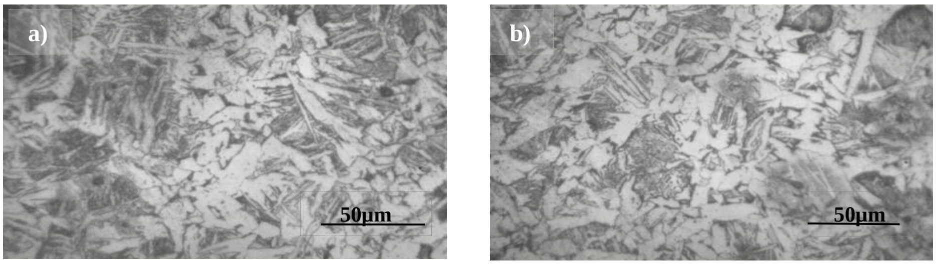

Fig. 1. Microstructure (a) at the edge & (b) at the centre of initial sample.

The white portion in the micrograph clearly indicates the presence of ferrite and the black portion indicates the presence of pearlite. Carburizing involves diffusion of carbon and chemical modification of the surface. Above the upper critical temperature, the austenite phase shows high solubility for carbon. So, carbon can easily diffuse through the surface of the sample. In fig 2, the micrographs of the carburized sample after annealing are presented. The microstructure showed the high presence of pearlite at the edge of the sample, which indicates carburizing, was performed perfectly. With the aid of ImageJ software, the micrograph was analyzed, and 48% pearlite were found at 434µm distance from the surface. The presence of high pearlite causes the increased hardness [4]. The hardness at the surface was found average 34 HRC and hardness at the core was average 21 HRC. The centre did not affected by carburizing, the microstructure contained ferrite and pearlite as like as initial sample.

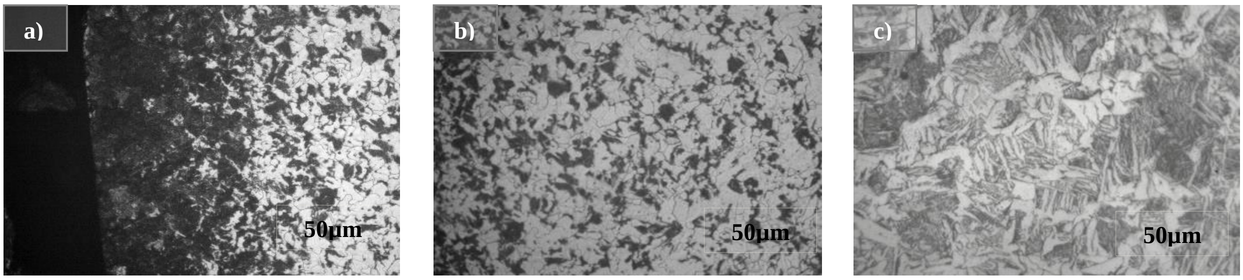

Fig. 2. Microstructure (a) at the edge (b) near the edge & (c) at the centre of carburized sample after annealing.

The micrographs of carburized sample after hardening and tempering were investigated (fig 3). The edge portion contained high carbon martensite, low carbon martensite and retained austenite. At the edge, three distinct layers were observed. The dark interior layer indicates low carbon martensite and the white spherical particle at the outer most layers indicate retained austenite. Away from edge, martensite was found, and the centre contained tempered martensite and retained austenite.

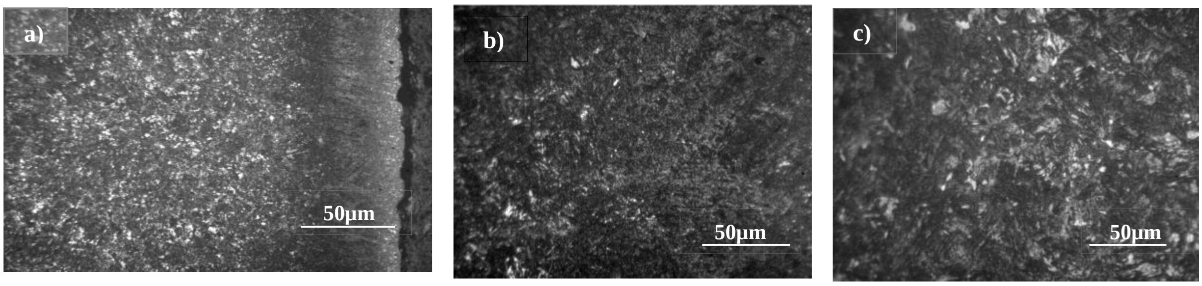

Fig. 3. Microstructure (a) at the edge (b) near the edge & (c) at the centre of carburized sample after hardening and tempering.

Surface hardness was measured in Rockwell hardness testing machine by placing the sample in transverse position. Micro-hardness was measured in Vickers hardness testing machine following zigzag path. The vertical distance of indentation from one point to another is also determined.

Table 3. The hardness value measured from surface to core

No of indentation from case to core	Distance of indentation from one point to another, μm	Hardness in vickers scale, HV	Hardness in HRC scale, HRC
1	0	456.1	45.7
2	152	488.3	48.2
3	456	549.5	52.4
4	914	456.0	45.7
5	1175	417.6	42.3
6	1617	378.9	38.6
7	1933	340.4	34.5
8	2464	334.7	33.8
9	2754	320.0	32.2
10	3143	305.2	30.4
11	3515	294.4	29
12	3947	282.3	27.4
13	4175	276.8	26.5
14	4685	272.5	25.9
15	5132	266.1	25.1

From this chat a micro-hardness profile was developed. Fig 4 shows a peak of maximum hardness at 52.4HRC at 456µm distance from the surface. At the centre, the core hardness is 25.1 HRC.

Therefore, a hard case and a soft core were observed after the investigation. From the microhardness graph (fig 4), the case depth was measured 456µm.

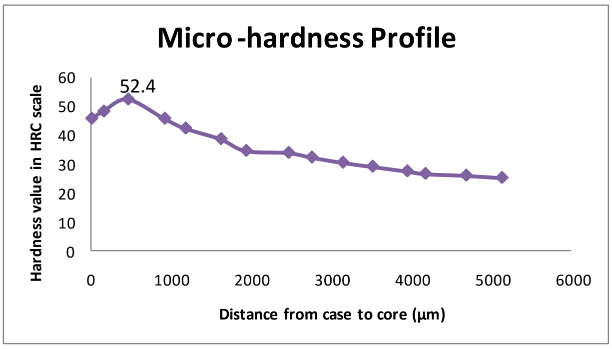

Fig. 4. Micro-hardness profile changes with distance from edge to core.

Though hardening was performed, it definitely couldn't affect the core at that extent. Low amount of martensitic transformation takes place due to presence of low carbon, so hardening and tempering hardly affect the low carbon steel [10]. Due to its soft core, it shows toughness and provides good fatigue properties [11]. These mechanical properties are highly needed for gear and shaft, however to achieve the wear resistance, surface hardening is the only solution for low carbon steel. In this paper, micro structural evolution was observed during carburizing treatment.

4. Conclusion:

In this paper, we observed the changes in microstructures in carburized steel with different heat treatment processes. Moreover, it is also investigated how hardness changes from case to core with the aid of a transverse micro-hardness profile. The case depth was measured from the microstructure at the edge of the sample. After performing annealing treatment, high amount of pearlite was found at the edge which causes increased hardness, but the inner side of the sample showed aggregation of ferrite and pearlite that reduce the hardness at the center. However, high carbon martensite formed at the outer surface in the carburized sample after hardening and tempering treatment that provides a hard surface. On the other hand, high amount of tempered martensite was found at the center of the sample that also causes a drop of hardness at the core.

5. References

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