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Evolution of Microstructure and Wear Resistance of Carburized Low Carbon Steel

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Abstract: The main aims of this present work were to investigate the microstructure and wear resistance of AISI 1020 during the pack carburization. The samples were prepared in a rectangular shape with a dimension of 5 mm X 25 mm X 2 mm for microstructure and hardness studies. Another set of samples with a dimension of 4.0 cm x 2.5 cm x 0.5 cm was prepared for the wear resistance performance. Both sets of samples were packed in the steel container which was tightly sealed. The carburizing atmosphere in the container was prepared by using mixtures of powdered charcoal and tamarind catalysts. The carburizing temperature of 950 °C with a fixed carburizing time of 2 hours was controlled for the pack carburizing treatment. The results exhibited that in the fresh condition, AISI 1020 mostly contained ferrite. Nevertheless, after carburization, quenching, and tempering process were carried out, the microstructures of the samples were changed from ferrite to pearlite and then martensite. An increase in the carbon content after carburization plays a major role in the evolution of the high hardness layers which subsequently enhanced the hardness and the wear resistance performance of AISI1020 after quenching and tempering.

Keywords: Pack carburizing, AISI1020, wear resistance

1. Introduction

Low carbon steel employed in a great number of mechanical components that need toughness, but still ductile and soft [1-5]. However, such essential properties of steel indicate the fact that its surface can be greatly degraded and subsequently quickly failed, especially when the steel components are subjected to some abrasive actions [6]. The common failure mode of the steel components under the abrasion load is well known as "wear" [7]. Therefore, wear-resistant improvement of any steel components is very important in the industries. Normally, the enhancement of engineering components undergoing wear can be done by the material selection [7]. High carbon and alloyed steels are often the first choices of materials for components utilized in abrasive applications [4-5]. The use of such materials in such severe conditions is useful but quite costly. Besides, the resources and availability of such materials are frequently limited, as well [4-5].

Low carbon steel usually composes of iron mostly alloyed with carbon and contains a small amount of other alloying elements, such as Manganese and Silicon [6-7]. This kind of steel can be heat-treated to improve its performance. Among many, pack carburizing is one of the most economical heat treatment processes for the case hardening of steel [8-9]. This process is composed of three steps: (1) Heating up for steel in the environment rich with carbon, (2) Quenching, and (3) Tempering. The proper microstructures got from each step plays a decisive role in controlling the hardness and wear-resistant properties. Hence, the information on the evolution of microstructures and wear resistance of low carbon steel during the pack carburization is vital for the development of steel components. Presently, many attempts have been made

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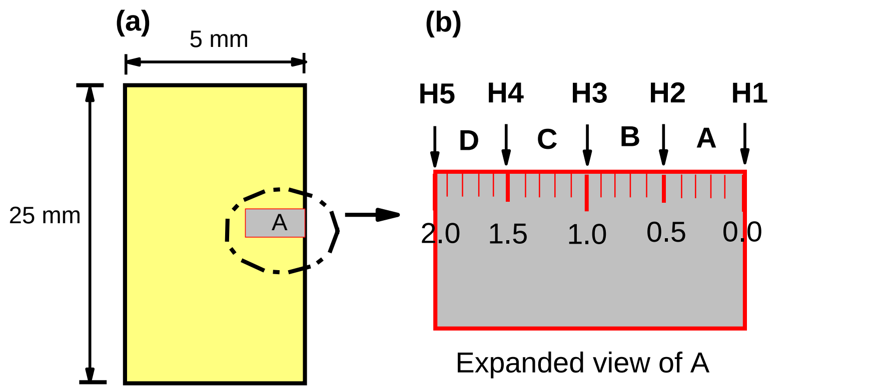
to study the pack carburization of steel. P.A. Ihom et al [10] studied the optimization of the carburization on the mechanical properties of steel. Demirkol et al [11] investigated the case depth of carburized steel on fatigue performance. T. G. Fadara et al [12] observed the corrosion resistance of carburized steel in hydrochloric acid services. The works carried out by researchers in the past are effective. Unfortunately, little attention has been paid to the microstructural and wear-resistant observation of carburized steel. Therefore, this paper aims to bridge the gap by investigating the microstructure and the wear resistance of carburized steel.

2. Experimental Procedures

The material of this investigation was the mild steel grade AISI 1020 with chemical compositions (% wt.) given as follows: C 0.18, Mn 0.51, Si 0.2, S 0.05, P 0.04, and Fe. The samples with a dimension of 5 mm X 25 mm X 2 mm were prepared for microstructure and hardness observation, the details of which can be seen from Fig. 1.



A, B ,C and D indicate areas where microstructure were evaluated.
H1 , H2 , H3 , H4 and H5 are the positions where hardness were measured.

Fig. 1 - (a) the schematic sketch of the samples for the microstructure; (b) hardness investigation

The microstructure observation was performed at positions labelled A, B, C, and D, and the hardness measurement was conducted at H1-H5. The positions of microstructure observation and hardness measurement were already given in Fig. 1. The pack carburization in this experiment was carried out at 900 °C with a holding time of 2 hrs. In this step, specimens were kept in the carburized steel container and the carburizing atmosphere in the container was prepared by the mixture of the charcoal and tamarind catalysts. Specimens were then quenched and subsequently tempered at 180 °C for 1 hr. The heat treatment conditions of this present investigation can be referred to elsewhere [13]. The carbon content added to the samples after the pack carburization was checked at positions as shown in Fig. 1. This carbon content checking was carried out by the spectrometer. The microstructure of samples without treatment and with total treatment was studied and compared by using light optical microscopy. Hardness profiles of mild steel subjected to the carburizing process were performed by using Micro Vickers hardness test model MHT-2. Another set of samples was prepared for wear resistance. The samples for the wear resistance performance were 4.0cm x 2.5 cm x 0.5 cm.

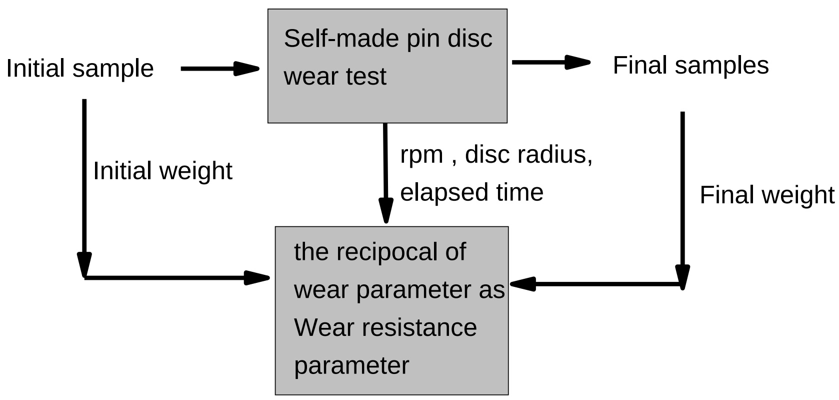


Fig. 2 – Schematic diagram for the wear test of this experiment

All the samples for the wear test were subjected to the pack carburization treatment and samples from each step were taken to the wear testing. The wear test was conducted on the self –made pin and disc machine. The sample was placed perpendicularly on a stationary plate where its surface can be pressed against the abrasive actions provided by the moving disc covered with the abrasive paper (Emery, 80-grade size). A load of this test was prepared by the lever mechanism and it was fixed at 15+/- 3 N with the constant speed of the moving disc at 300 rpm. The time for each test took 300 seconds and the radius of the abrasive wheel was set at 7.5 cm. Samples before and after the test were weighed and then divided by the density of steel to obtain the wear volume loss (ΔW), which can further be calculated to gain wear factor (K) [14]. In fact, the reciprocal of the wear factor value can be considered as the wear performance of materials [15] and this parameter is employed to indicate the wear resistance performance (WR) of carbon steel samples taken from every step of the pack carburization. The schematic diagram in illustrating the wear testing of this experiment is given in Fig.2. The equations used in this wear test are provided as follows [16].

$$\Delta W = \frac{W_{in} - W_{final}}{D} \tag{1}$$

Where W_{in} and W_{final} mean an initial and final weight, and D is density of steel (7.83 g/cm^3) [14].

$$WR = \frac{1}{K} = \frac{FS}{\Delta W} \tag{2}$$

Where F is normal force and S is the sliding distance which can be expressed as follow

$$S = \frac{(2\pi RN)}{60} . T \tag{3}$$

Where T is elapsed time, R and N mean disc radius and RPM of this test.

3. Results and Discussions

3.1 Microstructure Observation

Fig. 3 shows the initial microstructure of AISI 1020. Clearly, the microstructure of AISI 1020 is mainly composed of pearlite and ferrite, as pointed by the blue and red arrows.

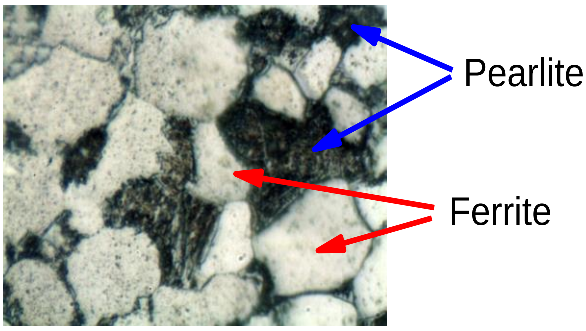


Fig. 3 - The microstructure of AISI 1020 without treatment

It can also be found that the amount of ferrite is much greater than that of pearlite. Basically, ferrite is naturally ductile and soft, but pearlite is tough. Thus, the initial microstructure of AISI 1020 exhibits good ductility, but not present adequate wear resistance. Fig. 4 exhibits the microstructure of AISI after carburization at 900 °C with the holding time of 2 hrs. Besides, the areas where the microstructure observation was carried out were also given, which can be referred to Fig. 1. Area “A” located at the surface of the samples shows pearlite. The microstructure of Area “B” contains pearlite with some ferrite. When the distance from the surface increases, the amount of pearlite decreases, but the amount of ferrite increases, as clearly seen from Area “C”. The microstructure of Area “D” displays the lowest amount of pearlite and the highest amount of ferrite. Normally, during the carburizing, carbon can diffuse into the low carbon steel by following reactions [17]

$$C + O_2 \rightarrow CO_2 \tag{4}$$

$$CO_2 + C \rightarrow CO \tag{5}$$

Carbon in the carburizer reacts with oxygen to form CO_2 and then CO_2 further reacts with carbon in the carburizer to generate CO. Basically, CO is known as the carrier of carbon to the low alloy steel, subjected to the carburizing process [13]. In practice, carbon atoms during the carburization can effectively be added into the samples, especially the distance from the surface between 0-1 mm. Thus, the change in the microstructures of samples after the carburizing process is caused by the diffusion of the carbon from the carburizing atmosphere. The presence of the pearlite at the surface indicates the area where the carbon has the highest concentration. On the other hand, the presence of the mixture of pearlite and ferrite means a decreased concentration of carbon. As the distance of the surface increases, the carbon concentration decreased, resulting in the formation of more ferrite, but less pearlite, as clearly seen in Fig. 4.

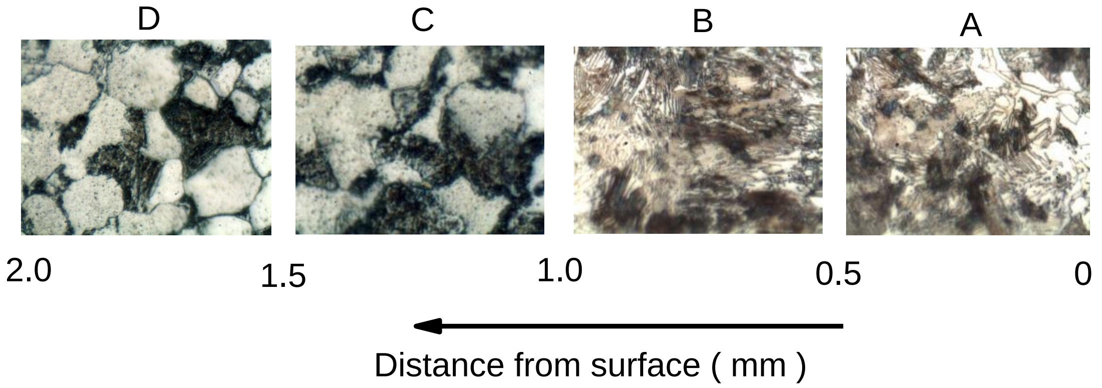


Fig. 4 - The microstructure of AISI 1020 after the carburizing process

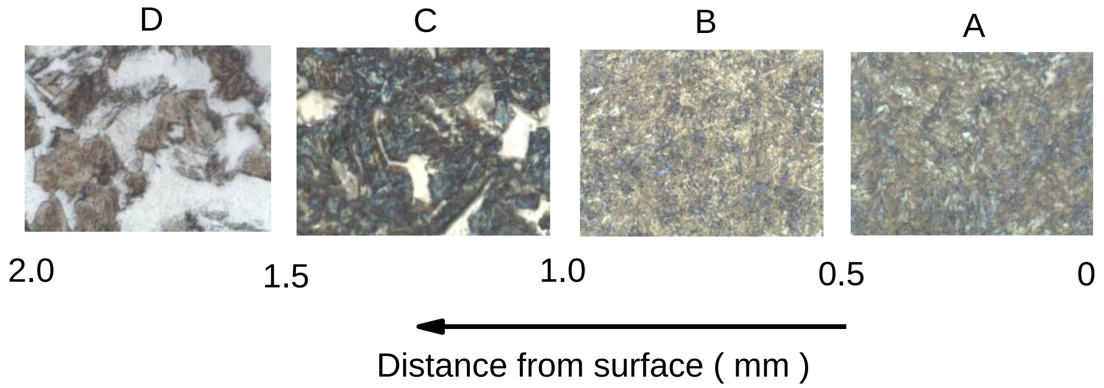


Fig. 5 - The microstructure of AISI 1020 after quenching and tempering

Fig. 5 shows the microstructure of AISI 1020 after quenching and tempering. Evidently, the area “A” shows a mixture of martensite. As the distance from the surface increased, the formation of more ferrite occurs. The area “B” displays a mixture of martensite and some ferrite. More amount of ferrite can be found in the area “C”. The area “D” exhibits a mixture of ferrite and pearlite. The presence of martensite and cementite can be attributed to the highest carbon content at the area “A” of the samples after the carburizing process. This high carbon-containing area in low carbon steel can be effectively hardened by quenching. The presence of ferrite and pearlite indicates the decreased carbon concentration as the distance from the surface increases. Normally, martensite is known as the hardest microstructure [18]. Hence, the surface of AISI1020 is already improved for abrasive applications.

Fig. 6 (a) shows the hardness evolution of samples with different treatment conditions and Fig. 5(b) shows the carbon content measured after carburization. As clearly seen in Fig. 6 (a), AISI 1020 in the initial condition shows the lowest hardness profile. However, after the carburization process, the carbon content increases, especially at the surface, as clearly seen from Fig. 6(b). Normally, AISI 1020 contains carbon at 0.18% wt. During carburization, carbon atoms can diffuse into samples, resulting in increased carbon content. Besides, increasing carbon content in Fig. 6(b) results in the change in the microstructure of the samples, as illustrated in Fig. 4. Usually, the increased carbon content in samples increases the hardenability. Thus, after quenching and tempering, samples show the highest hardness profile, as clearly indicated in Fig. 6(a). In fact, the high carbon content appears at the surface to 1 mm from the surface. This high carbon content layer facilitates the formation of the high hardness portion. The low carbon content is exhibited at the distance from the surface of 1-2 mm. This layer cannot provide the high hardness area, but the low hardness portion. Basically, the carbon concentration of carburized steels is governed by the diffusion of carbon atoms through the surface of steels. At the beginning of the carburizing process, the carbon atoms from a carburizing environment saturate immediately the steel surface, causing the maximum carbon content at the surface [19]. When carburizing process further proceeds, the surface layer of steels maintains saturated with the maximum carbon content and more carbon atoms tend to diffuse inwards, depending on the time of the carburizing process [20]. Hence, the microstructure of the samples after quenching and tempering offers the hard surface at the surface layer, but the next areas remain tough and ductile.

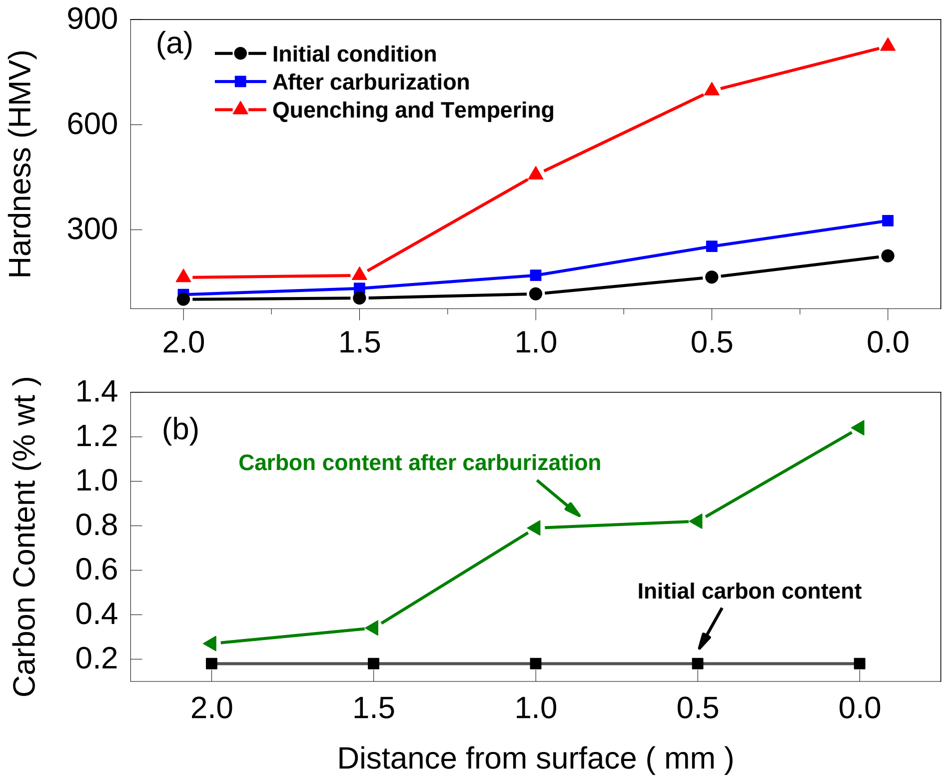


Fig. 6 - Hardness profile and carbon content (a) Hardness profile of AISI 1020 during the carburizing process; (b) Carbon content of AISI 1020 after carburization.

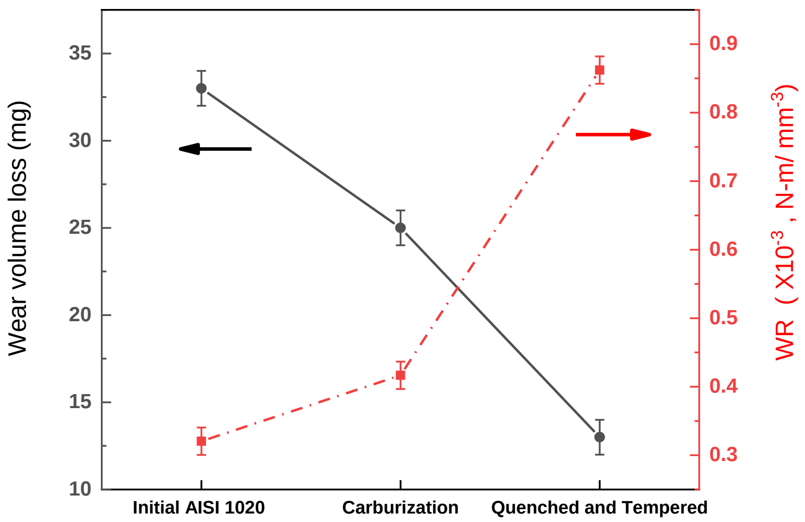


Fig. 7 - Wear resistance of samples at the fixed load of 15 N, 300 rpm, and 5 minutes

Fig. 7 shows the results of the wear volume loss and the wear resistance of samples from this experiment. It was found that AISI 1020 in the initial condition has the highest wear volume loss, following by the AISI 1020 with carburization and carburized AISI 1020 with quenching and tempering. It is also well known that the reciprocal of the wear parameter can indicate wear resistance of materials. This is because this parameter includes the effect of the sliding distance and normal force. Obviously, wear resistance of samples increases in order of initial AISI 1020, carburized AISI 1020 and Quenched and Tempered AISI 1020. Hence, the initial AISI has the lowest wear resistance performance. This is because AISI 1020 without treatment mainly contains ferrite, as previously shown in Fig. 3. The wear resistance performance can be developed by the pack carburization. The presence of pearlite as the tough microstructure in samples with pack carburization contributes to the increased wear resistance performance. As samples with pack carburization were quenched and tempered, the wear resistance performance significantly increases. The enhanced wear properties can be attributed to the increased carbon content during the carburization. The highest carbon content at the surface promotes the formation of martensite. This kind of microstructure is hard and strong naturally, thus providing the improved wear resistance performance of AISI 1020.

4. Conclusion

The microstructural evolution and the observation of the development of the hardness and wear resistance performance were successfully performed. The results from microstructure evolution indicated the transformation of the microstructure from the initial to the quenching and tempering conditions. In the initial condition, AISI 1020 mostly contained ferrite. However, after carburization, quenching, and tempering process were performed, the microstructures of the samples were altered from ferrite to pearlite and subsequently martensite. An increase in the carbon content after carburization facilitated the formation of the high hardness layers, which can improve the hardness and the wear resistance performance of AISI1020 after quenching and tempering.

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