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Reciprocating wear of mild steel carburized using Na_2CO_3-NaCl

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ABSTRACT – Experiments had been carried out to investigate the effect of carburization process, utilizing Na_2CO_3-NaCl as the electrolyte, on the wear resistance of mild steel. Increasing the duration of the carburization process resulted in higher peak hardness, greater case depth and amount of carbide in the grain boundaries, and larger but lesser retained austenite grains. The austenite microstructure formed in the steel carburized for 1 hour exhibited higher intergranular cracking and fracture resistance than the steel carburized for 3 hours. The difference in the cracking and fracture resistance could be attributed to the difference in the grain size and the amount of cementite in the grain boundaries. The results showed that steel with remarkable cracking, fracture, and abrasive wear resistance could be produced by removing the retained austenite grains from the surface of the carburized steel.

1. INTRODUCTION

The wear resistance of mild steel can be enhanced using carburization process which involves the intentional diffusion of carbon into the subsurface of iron-based alloys at high temperature. The carbon rich layer at the subsurface will transform to other microstructure (such as martensite and bainite) depending on the rate of cooling used after the carburization process. The formation of bainite and martensite on the subsurface of steel can result in a marked increase in the abrasive wear resistance of steel [1]. Molten salt containing toxic cyanide compound was the earliest compound used for the molten salt carburization process. Many research works have been carried out to eliminate the use of cyanide. More recently, we have developed an electro-carburization process utilizing non-toxic carbonate salts mixture as the electrolyte [2]. Several highlighted advantages of this process over the conventional method are the usage of non-toxic material, the efficient and rapid process that requires only 1-3 hours carburization process, the unnecessary addition of replenishment material for continuous source of carbon, a process that have capability to utilize abundant CO_2 gas as continuous source of carbon, and the potential for scalable electro-carburization process for larger production. This paper reports the study carried out to investigate the effect this carburization process on the wear resistance of mild steel.

2. EXPERIMENTAL

The wear behaviour of the non-carburized and carburized steel was investigated using a Ducom TR-20EV-M3 reciprocating tester. Tests were carried out at different combinations of normal load and frequency in ambient air for a duration of 30 minutes. Cemented carbide balls with a hardness 1600 HV were used to slide on the non-carburized (NC steel) and mild steel carburized for 1 (C1 steel) and 3 hours (C3 steel). The set up the carburization process had been described in details in ref. [2]. The mild steel had a nominal chemical compositions of 0.2 wt.% C, 0.19wt.% Si, 0.60 wt.% Mn, 0.014wt.% P and 0.018wt.% S, balance Fe.

3. RESULTS AND DISCUSSION

Figure 1 shows the variation of the hardness of the subsurface of the carburized steel. The C1 steel had a peak hardness of 727 HV at some distance from the surface and a case depth of 450 µm. The C3 steel had a higher peak hardness and case depth of 795 HV and 660 µm, respectively. Towards the core, the hardness reduced to that of the NC steel. Examination of the etched surfaces using an optical microscope and XRD analysis (peak at 2θ=43.8°) showed that the surfaces of C1 and C3 steel were dominated by retained austenite grains surrounded by grain boundaries (Fig. 2(a)). The diameter of the retained austenite grains on the surface of the C1 specimen measured using an optical microscope was found to be 10-30µm (Fig. 3(a-b)). C3 steel had larger austenite grains with diameter of 10-150 µm and greater amount of cementite in the grain boundaries (Fig. 3(c-d)). Precipitation of carbides at the grain boundaries was a result of the migration of the carbon in the austenite grains to the grain boundaries due to a marked reduction in the solubility limit of carbon in austenite during quenching. Martensite microstructure (Fig. 2(b)) could be observed after removing 5 µm thickness of material by polishing from the surface of the C1 steel. However, the martensite content at this subsurface was not high, therefore even a prolonged etching did not produce a dark martensite microstructure. Any retained austenite embedded in the martensite could be easily identified due to the difference in the colour of this microstructure (white) and martensite (dark). At 10-20 µm beneath the original surface, the martensite was darker but the grain boundary was less evident (Fig. 2(c)). Further polishing unveiled the region with the highest density of martensite. At this subsurface, no grain boundary was visible (Fig. 2(d)). Dark martensite with fine grain boundaries, occupied by numerous amount of cementite, appeared at the subsurface 5 µm beneath the original surface of the C3 steel. This showed that the C3 steel had higher density of martensite immediate below the surface dominated by austenite grains. Figure 1 shows that the carburized steel surface dominated by retained austenite microstructure, was softer than the martensite subsurface, 50-150 µm below the surface.

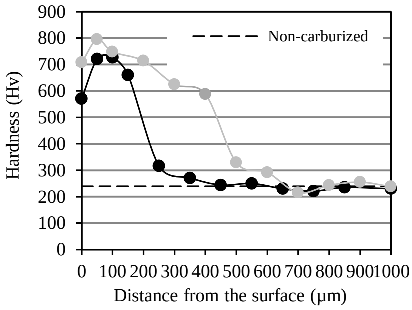

Figure 1 Variation of the subsurface hardness of the carburized steel.

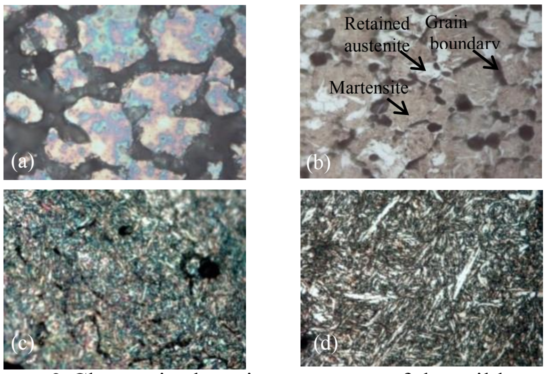

Figure 2 Change in the microstructure of the mild steel carburized for 1 hour with the depth of the subsurface (a) top surface (b) 5 µm below the surface (c) 20 µm below the surface (d) 100 µm below the surface.

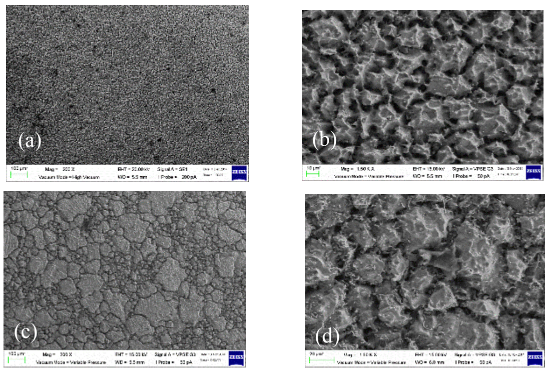

Figure 3 SEM images of the surfaces of the steel carburized for (a-b) 1 hour and (c-d) 3 hours.

The worn surfaces of the C3 steel showed evidence of intergranular cracking and fracture (Fig. 4(a)). Cracking and fracture were found to be confined in the worn surfaces dominated by retained austenite microstructure. However, no cracking and fracture appeared on the the worn surfaces of C1 steel dominated by austenite grains (Fig. 4(b)). C3 steel which had austenite grains with lower cracking and fracture resistance suffered greater volume loss than the C1 steel (Fig. 5). Removing 20 µm thickness of material from the surface of the C3 steel by grinding produced steel with surface and subsurface rich in martensite. This steel was also subjected to abrasion but suffered wear loss as compared to the C1 steel. These results showed that the presence of retained austenite reduced the abrasive wear resistance of the carburized steel. Pacheco and Krauss [3] reported that carburized steel with smaller austenite grains exhibited higher fatigue strength. Formation of cementite in the austenite grain boundaries during quenching in addition to the presence of other compounds such as manganese, silicon and carbon can act as fatigue crack initiators, resulting in intergranular cracking [4].

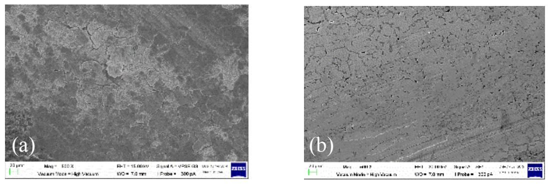

Figure 4 SEM images of the worn surfaces of the steel carburized for (a) 3 hours and (b) 1 hour at 50N 2Hz. Intergranular cracking are evident on the worn surface in (a).

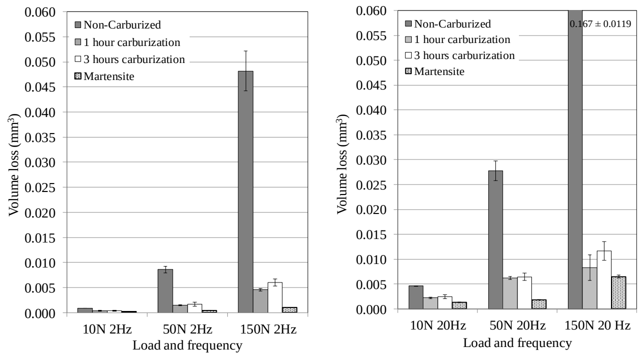

Figure 5 Volume loss after sliding tests using different combinations of frequency and load.

4. REFERENCES

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