Tribological behavior of Si-doped DLC coated layer on UIC60 steel

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ABSTRACT – Diamond like carbon thin film is widely studied and well known due to its excellent mechanical hardness and low friction coefficient performance. In this study, the nano-hardness and friction coefficient of non-doped DLC and Si-doped DLC coated on UIC60 steel were investigated. The results show that Si-doped DLC sample perform better than non-doped DLC sample in term of higher hardness and lower friction coefficient. Besides, the film thickness and Raman spectroscopy of both DLC sample were also investigated. As for both of the DLC coated sample, the SEM images showed a better resulting surface with mild fatigue crack and less wear fragment confined in the wear spot.

1. INTRODUCTION

The tribological behavior of rails has been widely studied by many researchers [1-2]. However, few papers have reported on the study of the application of DLC thin film coating on the UIC60 steel in industrial field. The present work aims to investigate the frictional behavior and nano-hardness of the Si-doped and non-doped DLC coated UIC60 steel and compare with the base material substrate UIC60. Finally, investigation on the structure and thickness of the DLC film produced was carried out using the Raman spectroscopy analysis and Alpha-step profilometer.

2. EXPERIMENTS

2.1 Preparation and pre-treatment process

The commercial rail material UIC60 was used as substrate in this study. The substrates were cleaned by ultrasonic cleaning process for 15 minutes in acetone and another 15 minutes in ethyl alcohol. And the substrates were kept in the chamber until the DLC deposition was carried out.

2.2 Deposition process

The model of the DLC coating instrument used in this experiment is KaDLC-800. Hexamethldisiloxane (HMDSO) deposition was first carried out in order to create buffer layer. Next, the DLC films of non-doped substrates (Is it "non-doped DLC films"?) were deposited using C_2H_2 reactant by PECVD method. Si-doped substrates were deposited using mixture of C_2H_2 and HMDSO reactants as gas sources.

2.3 Film thickness measurement

Alpha-step profilometer was used to measure the thickness of the DLC film produced. Film thickness of the DLC film was measured in order to investigate the factors related to the friction and wear behavior.

2.4 Hardness test

The model of the nano-indentation tester used was CSM NHTX. The nano-indentationtest was carried out on 3 samples: base material, non-doped and Si-doped DLC coated sample.

2.5 Tribological test

The sliding friction test was carried out using a ball-on-disc tribometer. A chromium ball with diameter of 6mm is used as the counterpart. The test was carried out by applying constant normal load of 10N with linear speed maintained at 4.19cms^{-1} for a total distance of 500m at ambient temperature. The test was also carried out for 3 types of samples.

2.6 Surface analysis

Raman spectroscopy and scanning electron microscope (SEM) were used to analyze the DLC film to explain the behavior of the tribological characteristics.

3. RESULTS AND DISCUSSION

The film thickness of non-doped DLC sample (1.95μm) was higher compared with the Si-doped DLC sample (1.46μm). The doped diamond like carbon film by nanoparticle such as silicon significantly decreased the residual stress in the film [3] and it is believed that it causes a thinner film being produced. The Raman results as shown in the Figure 1, the G-peak and D-peak for both samples are located at the same point. The values of the G-peak and D-peak for non-doped and Si-doped DLC samples are 1580 cm^{-1} and 1360cm^{-1} respectively.

As compared with the base material, the hardness of the both DLC coated samples are higher than the base material sample.

Among the two DLC coated samples, the Si-doped DLC sample has higher hardness than the non-doped DLC sample.

In contrast to carbon, Si can have only sp^3 hybridised bonds which may increase the three-dimensional inter-links.

Hence, increase in the dimensional inter-links of the sp^3 clusters can result in increasing hardness [4].

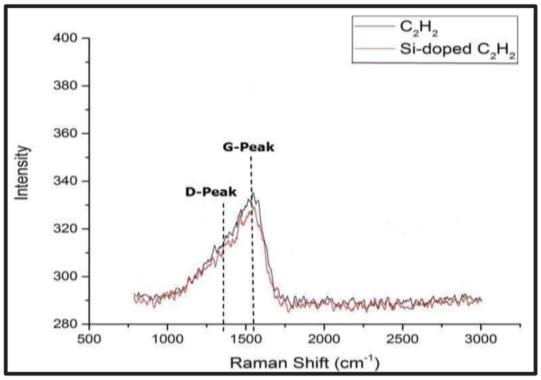

Figure 1 Raman graph of non-doped and Si-doped DLC sample.

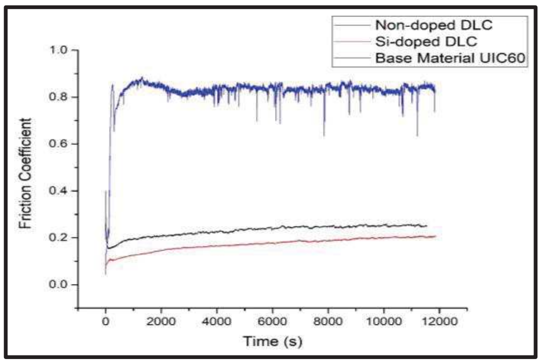

Figure 2 Friction coefficient of untreated, non-doped and Si-doped DLC sample.

Friction behavior in the Figure 2 shows that the base material has higher friction coefficient of 0.8-0.9 while both DLC samples show significantly lower friction coefficient ranging between 0.18-0.25. Between the two DLC coated samples, Si-doped DLC sample exhibits slightly lower friction coefficient than the non-doped DLC sample. Si-doped DLC sample has a higher surface roughness from the examination of surface profilometer than the non-doped DLC sample, and therefore has lower real contact area at the interfaces. Hence, Si-doped DLC sample performs a lower friction coefficient.

Figure 3, 4 and 5 show the SEM images for 3 types of sample after the friction test. The base material sample shows a more severe wear condition. The base material sample exhibits severe fatigue cracks besides the wear spot, and deep wear depth with abundance of wear fragments confined inside the wear spot. However, both DLC coated samples exhibit better resulting surface with mild fatigue crack and less wear fragment confined in the wear spot. However, delamination of DLC film is observed and visible in both DLC coated sample. The delamination of the DLC film suggests that the increasing trend of the friction coefficient is due to the sliding contact surface is no longer between DLC and chromium (static partner) but between the UIC60 and chromium.

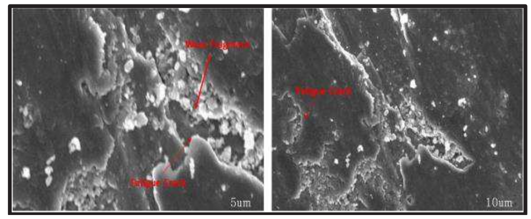

Figure 3 SEM images of base material sample.

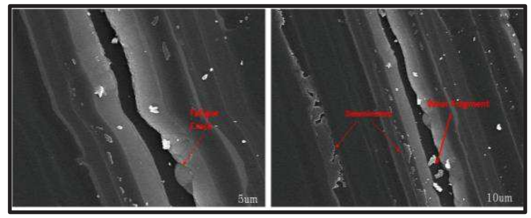

Figure 4 SEM images of non-doped DLC sample.

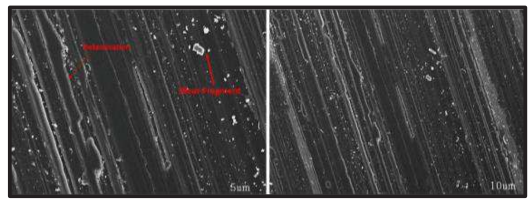

Figure 5 SEM images of Si-doped DLC sample.

4. CONCLUSION

The base material UIC60 steel, non-doped DLC and Si-doped DLC coated samples were examined in terms of their friction coefficient, nano-hardness and surface structure. As comparing the three tested samples, Si-doped DLC sample exhibits better tribological characteristics with higher nanohardness and lower friction coefficient.

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