P. SRISATTAYAKUL, C. SAIKAEW, A. WISITSORAAT

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EFFECTS OF HARD CHROME AND MoN-COATED STAINLESS STEEL ON WEAR BEHAVIOUR AND TOOL LIFE MODEL UNDER TWO-BODY ABRASION WEAR TESTING

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The objectives of this study were to investigate the effect of the electroplated hard chrome (HC) and the MoN-coated AISI 316 stainless steel coatings on weight loss under two-body abrasion wear testing and to predict the tool life of both materials used as a fishing net-weaving machine component, namely the hook. Both materials were used to carry out the wear experiments under two-body abrasion behavior. These specimens were wear tested with the in-house wear testing apparatus base on ASTM: G133-05 standard. The Taylor's equation was used to formulate the tool life model whereas the Monte Carlo simulation was used to predict the tool life of the machine part. The results showed that the MoN-HC exhibited higher wear resistance than that of the HC.

Key words: AISI 316 stainless steel, coatings, abrasion wear testing, properties, Taylor's equation, Monte Carlo

INTRODUCTION

The two-body abrasion process is a hard particles matched two-surface damages during relative sliding [1]. It is observed when a matter comes into contact with abrasive material [2]. Two-body abrasive wear was a type of wear which was frequently found in manufacturing processes such as drilling, turning, milling operations, and other industries.

Applications of coated machine-parts increase the efficiency and quality of the parts. Sovilj et al. examined the effect between base material and TiN-hard coating [3] whereas Bidulsky et al. studied the sliding wear between sintered and PVD coated surfaces on chromium steel [4].

Deposition metal nitrides were popularly studied for wear resistant coatings because this coating method increased the wear resistant properties e.g. high hardness, low compressibility and good thermal/chemical stability [5]. The properties of MoN are typically important for wear resistance, crack resistance, and corrosion resistance [6-8]. Srisattayakul et al. studied the three coating factors affecting the elastic modulus and weight loss of the MoN coating on a fishing net-weaving machine component, namely the hook for improving the quality of the hook [9, 10]. The machine component, which is normally made of stainless steel is very important for producing the fishing net. If the component is not of good quality as shown in Figure 1, it causes damage to the fishing net. The fishing net manufacturer needs to replace the new hook before the component wears out. Hence the prediction model of the component life of the fishing net-weaving machine component should be studied.

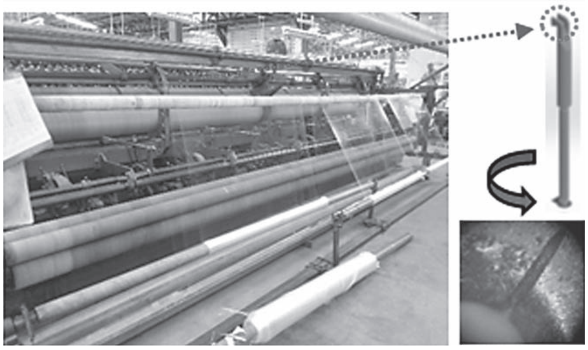

Figure 1 The damage to hooks on fishing net weaving process.

Previously, many researchers used the Taylor's equation as a powerful methodology for the tool life prediction models. Karandikar et al. used this equation in conjunction with the Markov Chain Monte Carlo approach for the tool life prediction model of carbide tool for turning MS309 steel work material [11]. The tool life model and tool wear mechanism analysis of carbide tools for martensitic S41000 and supermartensitic S41426 turning were investigated using the Taylor's equation [12].

Since the two-body abrasion is a stochastic process and the worn surfaces reveal strong statistical characteristics, the classical mathematical models are not appropriately used to predict the wear rate. Fang et al. verified that the relations of material hardness, particle size and normal load with wear rate between the Monte Carlo simulation and the two-body abrasion tests were

P. Srisattayakul, C. Saikaew, Department of Industrial Engineering, Khon Kaen University, Khon Kaen Thailand and A. Wisitsoraat, National Electronics and Computer Technology Center, Pathumthani Thailand.

in good agreement [1]. Furthermore, Fang et al. also employed the Monte Carlo simulation to compare the plastic deformation wear prediction with the three-body abrasion experiments using spherical abrasive particles with different distribution sizes [13].

In this work, the influence of the electroplated hard chrome (HC) and the MoN coating on the weight loss under two-body abrasion wear testing was investigated. In addition, tool life models of the hook were created for the HC and the MoN-coated AISI 316 stainless steel using Taylor's equation and Monte Carlo simulation in order to improve the quality and operational tool life of the hook.

EXPERIMENTAL PROCEDURE

The hook was made of AISI 316 stainless steel, which chemical elements included 0,2 %-0,3 %C, 18 %-23 %Cr, 1,0 % - 1,5 %S 1,25 % - 2,50 %Ni and 1 %Mn. The mechanical properties of the specimen were density 8,07 Mg/m^3, compressive strength 310 MPa, ductility 0,51, elastic limit 310 MPa, endurance limit 307 MPa, hardness 2 200 MPa, poisson's ratio 0,275, shear modulus 82 GPa, tensile strength 620 MPa, young's modulus 205 GPa and melting point 1 673 K.

Previously, the sliding wear tester used principle between the pin-on-disc (ASTM: G99) and block-on-ring (ASTM: G77) for lower hook of fishing net-weaving machine [14]. The two-body abrasive wear characteristics of MoN, MoC, and MoCN coatings by DC magnetron sputtering on AISI 316 stainless steel were investigated using test a reciprocating pin-on-flat which is homologous to that of ASTM G133-05 standard [15]. In this work, the reciprocating dry sliding wear test was prepared the wear tester according to the ASTM: G133-05 standard. The schematic illustration of the wear tester apparatus is shown in Figure 2.

The specimens were separated into two groups namely, HC coated on stainless steels (SS) by electroplating (SS-HC) and MoN coated on SS-HC by DC-magnetron sputtering (MoN-HC). All specimens were subjected to the wear test condition for SiC-abrasive paper (Grit#1000), with in applied load range of 5 N and 10 N, a speed of 70 rpm, a stroke length of 15 mm and continuous sliding time range of 40 min with four replicates in each test condition.

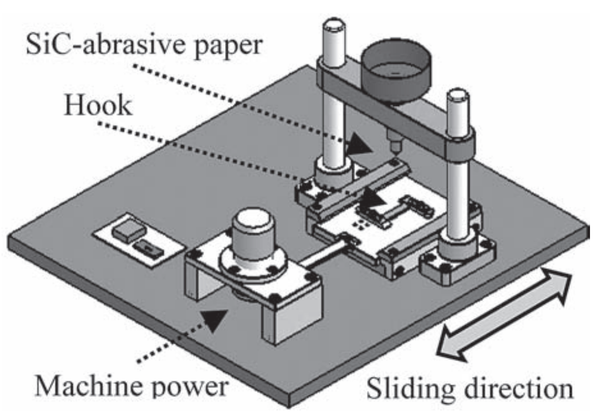

Figure 2 Schematic illustration of the wear tester

RESULTS AND DISCUSSION

The weight loss was used to characterize the influences of SS-HC and MoN-HC on the weight loss under two-body abrasion wear testing with the testing time range from 40 to 880 min. The weight loss of the hook has a major negative effect on the surface and the quality of the component and the fishing net when the weight loss value reaches a certain level of 0,05 g. The weight loss values of both SS-HC and MoN-HC were plotted as a function of sliding time with applied load range of 5 N and 10 N, which is illustrated in Figure 3. It was noted that weight loss increased with the increase of applied load for both materials. The MoN-HC depicted less serious wear than the SS-HC. This indicated that MoN-coated AISI 316 stainless steel had longer life than the electroplated hard chrome for producing the fishing net-weaving machine component.

Life of the hook model was derived from Taylor's equation based on the results of the weight loss values as the function of sliding time with applied load range of 5 N and 10 N. The basic Taylor's equation was developed to relating life of the hook to the main wear experimental parameter (i.e., applied load) shown in Equation (1):

$$L(T)^n = C \tag{1}$$

where T is the life of the hook (min), L is the applied load (N). Furthermore, n and C are the life of the hook constants, whose values depend on wear testing conditions and workpiece materials.

Based on the results as illustrated in Figure 4, the sliding times corresponding to the average weight loss values at the threshold level of 0,05 g with applied load range of 5 N and 10 N of both materials are shown in Table 1. These values were used to develop the life models of both materials by the Taylor's equation.

The life models of both materials modified by the Taylor's equation were formulated as follows:

$$L(T)^n = C$$

$$n\log T - \log C = -\log L$$

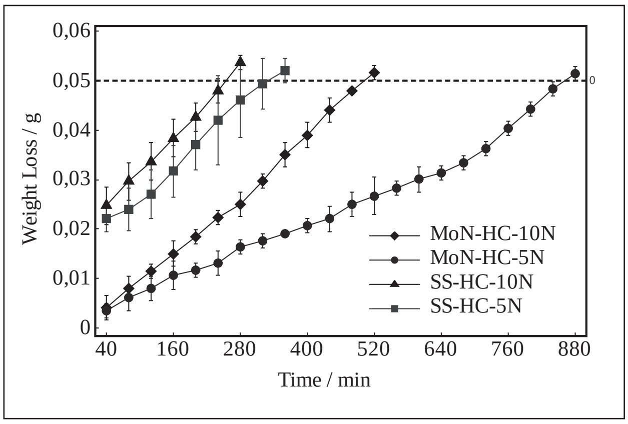

Figure 3 Average weight loss versus sliding time of SS-HC and MoN-HC

Table 1 **Sliding time corresponding to the average weight loss values at the level of 0,05 g of SS-HC and MoN-HC**

SS-HC		MoN-HC	
5 N	10 N	5 N	10 N
320 min	250 min	320 min	250 min

The unknown constants of the models were calculated based on the modified Taylor's equation and the results in Table 1. Therefore, the life model of SS-HC was obtained as follows:

$$L(T)^{1,278} = 28\,135{,}7845 \tag{2}$$

which was expressed as Equation (3)

$$T = \left(\frac{28\,135{,}7845}{L}\right)^{\frac{1}{1,278}} \tag{3}$$

Similarly, the life model of MoN-HC was determined as follows:

$$L(T)^{2,8072} = 53948\,348{,}77 \tag{4}$$

which was expressed as Equation (5)

$$T = \left(\frac{53\,948\,348{,}77}{L}\right)^{\frac{1}{2,8072}} \tag{5}$$

Not only the life models of both materials can be estimated by the modified Taylor's equation, but variation of the life values of both materials can be achieved by using a Monte Carlo simulation. In fact, the applied load normally varies during the wear testing on the wear testing apparatus. Hence the Monte Carlo method applied the principle's normal distribution by specifying the mean and standard deviation for input at a confidence level of 90 %. The applied load consisting of 6 levels (5N, 6N, 7N, 8 N, 9 N and 10N) was assigned as the input to generate random data set for each applied load by specifying the mean for the applied load and the standard deviation for the variation of each applied load. Each level of applied load generated the random data set of 1 000 that followed normal distribution. The result of the Monte Carlo simulation for the life models of the SS-HC and MoN-HC is presented in Figure 4.

Considering the Monte Carlo simulation for the life models of the two materials, all life values of the MoN-HC exhibited a longer life than those of the SS-HC at all applied loads at least 100 %. In addition, variations of life values at each of applied loads of the MoN-HC were larger than those of the SS-HC. All life values of the MoN-HC were higher than those of the SS-HC that may be attributed to their greater hardness and higher surface smoothness.

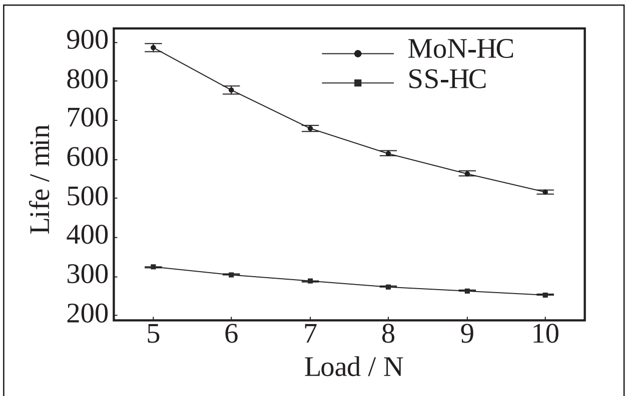

Figure 4 The Monte Carlo simulation for the life models of SS-HC and MoN-HC

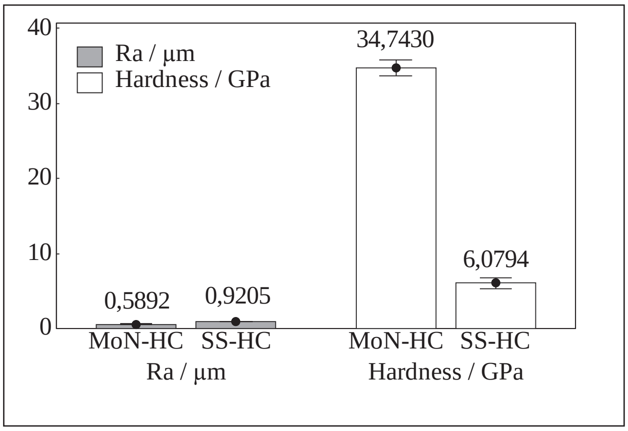

Figure 5 Hardness and Ra- values of SS-HC and MoN-HC

The hardness values of the specimens were measured by a nanoindenter. According to Figure 5, the nano-indented hardness values of MoN-HC (~ 34,7430 GPa) were higher than those of the SS-HC (~ 6,0794 GPa). The average roughness values (Ra-values) of the MoN-HC (~ 0,5892 µm) were lower than those of the SS-HC (~ 0,9205 µm) as shown in Figure 5. Since MoN-coated AISI 316 stainless steel by sputtering tends considerably reduce Ra-values, the sputtered MoN is good for surface smoothing.

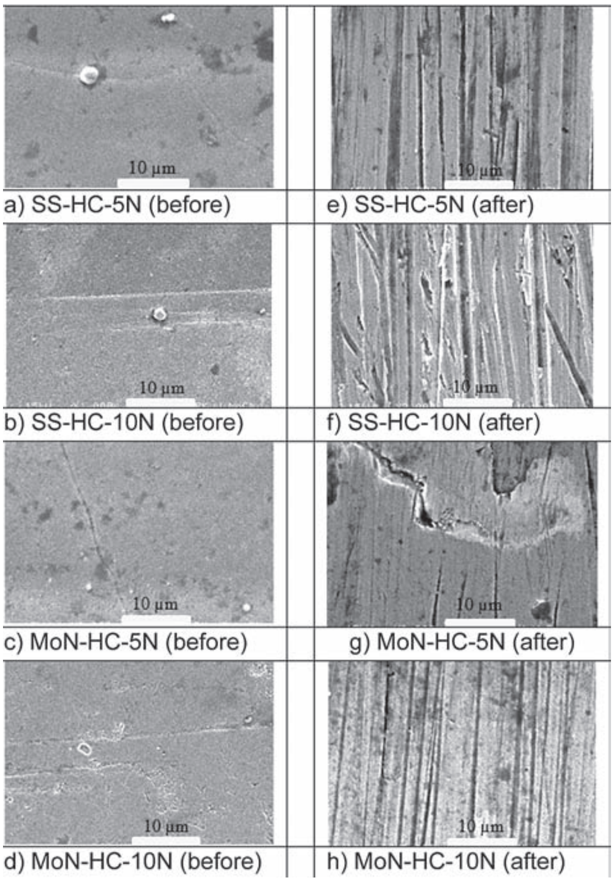

Figure 6 The SEM micrographs of SS-HC and MoN-HC

Figure 6 demonstrates the scanning electron microscope (SEM) micrographs of specimens under the applied load range of 5 N and 10 N. Before the wear test, the SS-HC (Figures 6 (a) and (b)) showed rather rough surface free from pits, dimples and line groves while the MoN-HC (Figures 6 (c) and (d)) found little. After reciprocating test until reaching the weight loss of 0,05 g, the surfaces were mostly worn in parallel line groves along the reciprocating directions as shown in Figures 6 (e), (f), (g) and (h). It was noted that the SS-HC had larger pits, dimples and line grooves more than those of the MoN-HC. In addition, the applied load affected the quantity of defects which appeared on the surfaces.

CONCLUSIONS

In this work, the Taylor's equation in conjunction with Monte Carlo simulation was used to construct the tool life model for prediction of the electroplated hard chrome and the MoN-coated AISI 316 stainless steel used as the fishing net-weaving machine component under two-body abrasion wear testing. Base on the comparison of test results, the following conclusions may be included:

- The MoN-HC coating showed the best life behavior compared with the SS-HC.
- All life values of the MoN-HC were longer than those of the SS-HC at all applied loads at least 100 %.
- The variations of life values at each of applied loads of the MoN-HC were larger than those of the SS-HC.
- The SS-HC had larger pits, dimples and line grooves more than the MoN-HC.

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Note: Allen F. Doyle U.S.A., is responsible for the translation of the paper into the English language, Thailand