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Study in the Mechanisms of Formation of Transfer Film under the Condition of Wear of Steel AISI1020 by Natural Rubber

DE-GUO WANG [1] SI-WEI ZHANG [1] REN-YANG HE [1] and MING-YUAN LI [2]

[1] *School of Mechanical and Electronic Engineering, University of Petroleum, Beijing, 102200, CHINA*
[2] *School of Chemical Technology and Engineering, University of Petroleum, Beijing, 102200, CHINA*

The mechanisms of formation of transfer film under the condition of wear of Steel AISI1020 by natural rubber were investigated. The transfer film was observed and the formation mechanisms were clarified. The formation process of transfer film on the worn surface of the steel could be divided into two stages. Firstly, the adhesive layer emerged on the worn surface of the steel by adhesion of natural rubber, in which the macromolecular chains of natural rubber joined to the surface of the steel by Van der Waals' force. And then, the iron atom and metal oxide reacted with the macroradicals of natural rubber in the adhesive layer and produced Fe-polymer compound. As a result, the transfer film was formed on the worn surface of the steel. The transfer film was joined to the worn surface of the steel by the chemical bonds and electrostatic force.

Keywords: Natural Rubber, Steel, Transfer Film, Formation Mechanism

1. INTRODUCTION

Since 1960's. the wear of metal by rubber has been studied [1-4], but some chemical reaction did not arouse general concern. In early nineties, Zhang and his coworkers started again this field and they found a special film existing on the worn surface of metal during the wear of metal by rubbers [5-7]. In this paper, the formation mechanisms and the properties of this transfer film for the steel-natural rubber tribo-couple are investigated.

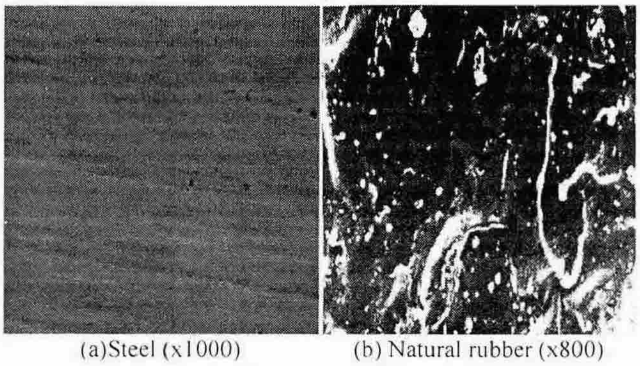
2. EXPERIMENTAL METHOD

Wear tests were carried out by using FALEX friction and wear machine with a ring-on-disc sliding couple. The ring with outside diameter of 40mm and inside diameter of 34mm is made of Steel AISI1020. The disc with 55mm diameter and 6mm thickness is made of natural rubber (NR) materials. Experiments were performed at room temperature under a normal load of 22.3N and a sliding speed of 100r/min.

3. RESULTS

3.1 SEM Examination

The SEM morphologies of worn surfaces of the steel and natural rubber are shown in Figure1.



(a)Steel (x1000) (b) Natural rubber (x800)

Fig. 1 SEM Micrographs of the worn surfaces

3.2XPS Analysis

The elements composition for original and worn surfaces of the steel and natural rubber is shown in Table 1.

Table 1 Elements composition for original and worn surfaces

Samples		Atomic concentration (%)					
		C_{1S}	O_{1S}	Fe_{2P}	Cl_{2P}	N_{1S}	S_{2P}
NR	Original surface	93.3	6.70	/	/	/	/
	Worn surface	93.05	6.95	/	/	/	/
Steel	Original surface	45.75	39.21	11.77	0.19	2.44	0.63
	Sputtering 0 min	56.19	33.13	7.05	0.33	3.08	0.21
	Sputtering 2 min	39.08	38.64	20.25	0.28	1.55	0.19
	Sputtering 7 min	40.63	28.44	29.52	0.23	0.94	0.25

The XPS spectra of both original and worn surface of the steel are shown in Figure 2.and Figure 3.

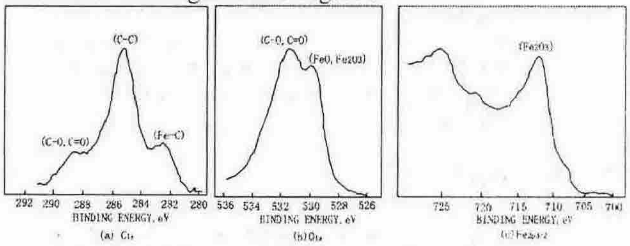


Fig.2 XPS Spectra of the worn surface of original steel

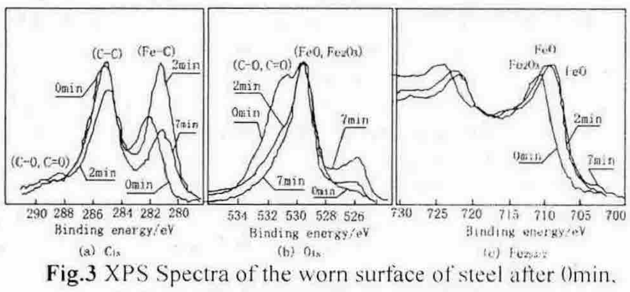


Fig.3 XPS Spectra of the worn surface of steel after 0min, 2min and 7min sputtering respectively

The binding energy of C_{1s} and O_{1s} and the analysis percent of function group for original and worn surface of natural rubber are shown in Table 2.

Table 2 The binding energy of C_{1s} and O_{1s} and percent of function group for original and worn surface of natural rubber

Surface of NR	Binding energy (eV)		Percent(%)				
	C_{1S}	O_{1S}	C=O	C-O	C-C	Carbon	Graphite
Original	285.2	532.2	1.56	4.18	85.21	6.53	2.51
Worn	285.1	532.6	1.67	4.36	84.46	4.29	5.23

The element analysis shows that there existed a transfer film on steel worn surface and some reactions took place in the subsurface of the steel.

3.3 FT-IR analysis

The FT-IR spectra of natural rubber surface before and after wear are shown in Figure 4.

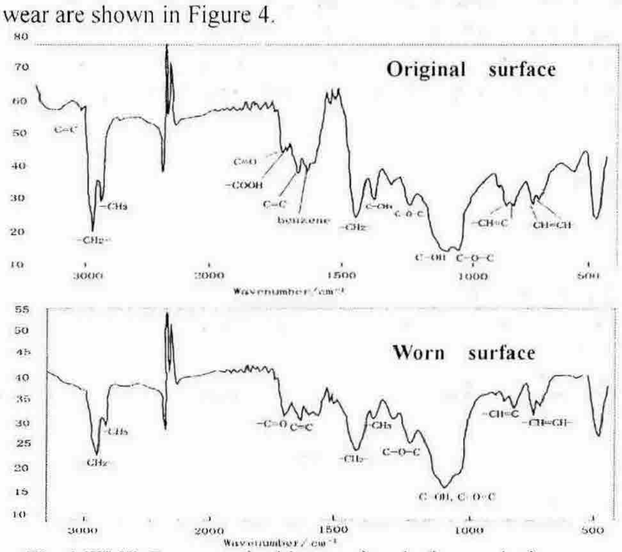


Fig.4 FT-IR Spectra of rubber surface before and after wear

It could be inferred that macroradicals produced and oxygenated degradation occured on the worn surface of the natural rubber.

3.4 Contact angle

The contact angles (or wet angles) for the original and worn surface of the steel were directly measured respectively, namely, the contact angle is taken an average over the contact angles of three points on each surface

4. DISCUSSION

3.1 The formation of transfer film

According to the surface morphology and the change of elements and chemical functional groups, the formation of transfer film could be divided into two stages, which are the occurrence of adhesion layer and the formation of transfer film.

The adhesion layer emerged on the worn surface of the steel by adhesion of natural rubber, in which the macromolecular chains of natural rubber adhere to the surface of the steel by Van der Waals' force of intermolecular chains [8]. And then, the iron atom and metal oxide reacted with the macroradicals of natural rubber in the adhesive layer and produced Fe-polymer compound. As a result, the transfer film was formed on the worn surface of the steel by the chemical bonds and electrostatic force

3.2 Properties of transfer film

The transfer film is different from the substrate materials (steel) because it has the anti-friction performance in the view of tribology. This conclusion can be proved by the experimental results that the frictional torque reduced from the 26N.m to 6N.m after the transfer film formed. This transfer film could inhibit the oxygen in air reacted with element Fe by covering the metal surface. Thus, the debris of metal oxides can not produce and the abrasive wear will be restricted to a certain extent.

It is found that the wet angle on the worn surface of the steel with transfer film increased evidently. Therefore, the hydrophilicity of worn surface has been improved and the worn surface has the ability of lipophilicity. It could be deduced that the surface energy of metal surface with transfer film decreased obviously.

5. CONCLUSIONS

The formation of transfer film on the worn surface of the steel can be divided into two stages. (1) The adhesion transfer layer produced on the worn surface of the steel by adhesion of natural rubber, and the macromolecular chains of natural rubber joined to the surface of the steel by Van der Waals force of intermolecular chains. (2) The transfer film formed on the worn surface of the steel by a series of reactions in the adhesive transfer layer and producing Fe-polymer compound. The transfer film was joined to the worn surface of the steel by the chemical bonds and static electrification force.

6. ACKNOWLEDGEMENTS

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