STUDY ON ONE SELF-REPAIR TECHNOLOGY APPLIED TO WORKING EQUIPMENT

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Abstract

The tribological properties of stratified silicate self-repair material was studied by using end-face friction and wear tester. The microstructure, composition, and mechanical performance were investigated by using SEM, EDS, and nano indenter. Besides, the effects on energy-saving and emission reduction for stratified silicate were confirmed by being applied to two buses. The results show that stratified silicate self-repair material can reduce observably surface roughness of tribo-couple, improve lubricating status of tribo-couple and reduce frictional resistance. Moreover, stratified silicate additive in lubricating oil facilitated a high-hardness surface repair layer rich in elements of carbon, iron, silicon, aluminum and magnesium arise on worn surface. The self-repair layer could actualize non-disassembly repairing for worn parts, prolong service time of equipments, and insure the energy saving and exhaust reducing steadily.

Key words: stratified silicate, self-repair, tribological property, nano-hardness

1 Introduction

More than one third energy consumption all over world was due to friction and wear. Wear is one of the main reasons causing equipment parts to be damaged and causes 80 percent of mechanical faults [1]. In china, a large number of mechanical equipments need repair every year. However, these mechanical equipments must still work in order to complete production target or because of other reasons. Energy consumption per unit of output value would rise, and excessive usage makes equipments be damaged. In order to explore and develop self-repair technology of running equipments and realize non-disassembly repairing of abrasion parts, researchers and experts at home and abroad have made much effort.

Former studies show that stratified silicate possesses unique metastable stratified crystal structure, and there are large numbers of unsaturated bonds that can adsorb not only metallic ions but also anion clusters and organism in fracture surface [2-3]. The adsorption ability and chemical activity of stratified silicate increase with specific surface area increasing rapidly when stratified silicate is heated to remove hydroxyl between 500 degrees centigrade to 600 degrees centigrade. A high-hardness self-repair layer is easy to come into being because of additive possessing the unique stratified crystal structure. Thus abrasion parts could be maintained and repaired under the circumstance of non-stopping and non-disassembly repairing [4-7]. In this paper, serpentine stratified silicate was prepared into self-repair powder with an average particle diameter of 0.5 micrometer at methods of ultra-fine crushing and surface modification. Besides, the tribological properties and the effect of repairing on friction surface of ultra-fine powder were investigated.

2 Tribological properties of stratified silicate self-repair material

2.1 Experiment

As the lubricating medium, 0.2 percent by weight of stratified silicate self-repair material was added into 15W/40CD diesel engine oils. Friction and wear tests were performed on an end-face friction and wear tester under oil lubricating with a load of 200 N and a speed of 500 rpm for 8 hours. The tribo-couple were made from 45 # steel. A surface roughness tester was used to measure the surface roughness of worn surface. The microstructure, composition and nano-hardness of worn surface were investigated respectively by using scanning electron microscopy (SEM), energy dispersive spectrometer (EDS) and Nano Test 600.

2.2 Results and discussion

Fig. 1 shows curve of friction coefficient versus time. Friction coefficient of tribo-couple is about 0.09 under base oil lubricating conditions, however, friction coefficient decrease to 0.03 when stratified silicate self-repair additive was added into base oil. The decrease of friction coefficient proves that stratified silicate self-repair material has good tribological performance. Fig. 2 shows that friction temperature of tribo-couple varied with time. Under different lubricating conditions, temperature of tribo-couple decreased obviously after stratified silicate self-repair additive was added into base oil, which is corresponding with the change trend of friction coefficient. The lower frictional force and friction coefficient were, the less heat energy was created. It was due to addition of stratified silicate self-repair additive.

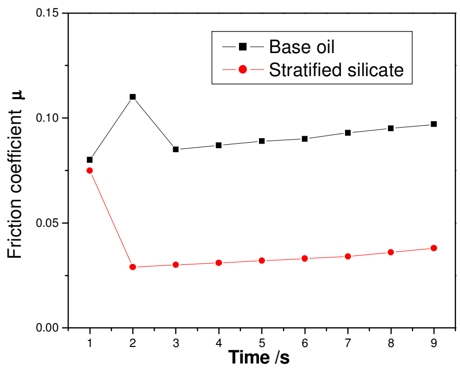


Fig. 1 Curve of friction coefficient versus time

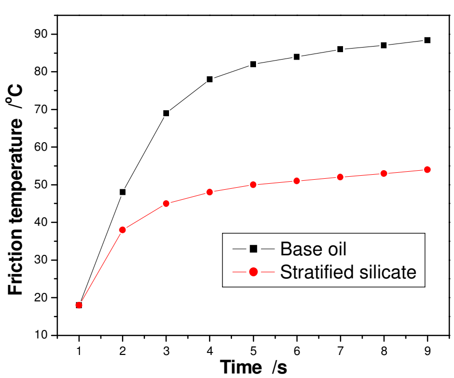
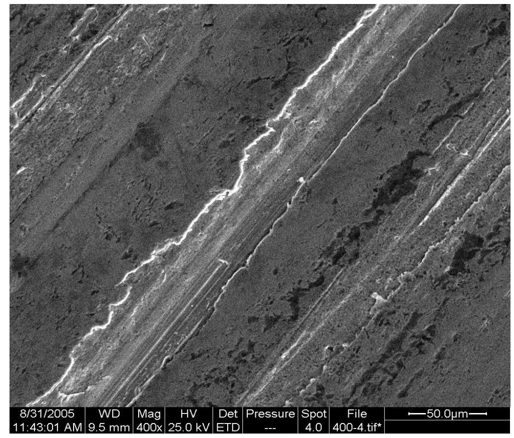
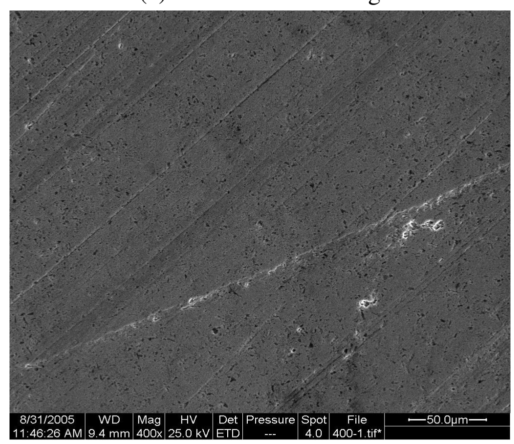


Fig. 2 Curve of friction temperature versus time

Fig. 3 shows micrographs of worn surface of tribo-couple sliding under different oil lubricating conditions. Fig. 3a shows many deep scratches and obvious adhesion phenomenon emerging on worn surface of 45 # steels sliding under base oil lubricating, which was suggested that the worn mechanism should mainly be adhesive wear and abrasive wear. Fig. 3b shows more smooth surface morphology on worn surface of tribo-couple sliding under mixture of stratified silicate self-repair additive and base oil lubricating conditions.



(a) Base oil lubricating



(b) Self-repair additive lubricating

Fig. 3 Micrographs of worn surface of tribo-couple sliding under different lubricating conditions

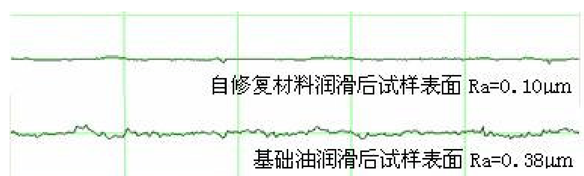
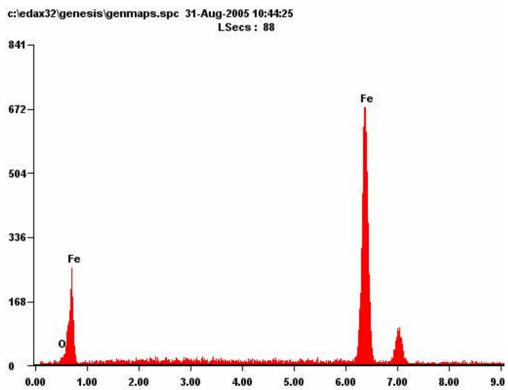


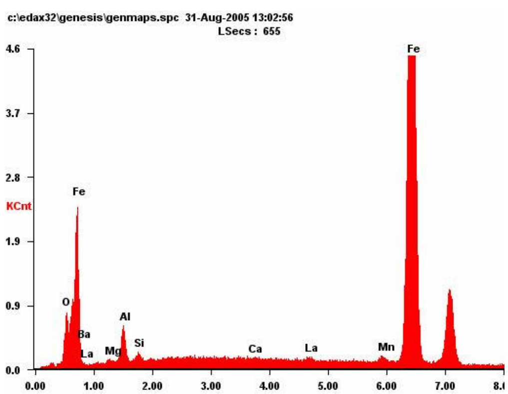
Fig. 4 Surface roughness of worn surfaces of tribo-couple sliding under different oil lubricating conditions

Fig. 4 shows surface roughness of worn surfaces of tribo-couple sliding under different oil lubricating conditions. The surface roughness of worn surface of tribo-couple decreased from 0.38 μm of base oil lubricating to 0.10 μm of addition of stratified silicate self-repair material. It is considered that lubrication status of tribo-couple change from boundary lubrication of base oil lubricating to mixed lubrication (boundary lubrication and liquid lubrication) of addition of stratified silicate self-repair material.

Fig. 5 shows EDS analysis of elements on worn surface sliding under different oil lubricating. The results show that the elements on worn surface sliding in base oil are mainly element Fe from 45# steel matrix, however the elements on worn surface sliding in mixture oil include elements Fe, Al, Mg, and Si, etc. It was ensured that elements Al, Mg, and Si were from stratified silicate self-repair material.



(a) Base oil lubricating



(b) Self-repair additive lubricating

Fig. 5 EDS analysis of elements on worn surface

Table 1 Hardness and modulus of elasticity of worn surfaces sliding under different oil lubricating conditions

Mechanical properties	Lubricating conditions	
	Base oil lubricating	Self-repair additive lubricating
Hardness /GPa	3. 85	5. 98
Modulus of elasticity /GPa	238. 9	254. 1

Table 1 shows hardness and modulus of elasticity of worn surfaces sliding under different oil lubricating conditions. The harness of worn surface of tribo-couple increased as high as 55 percent, i.e., from 3.85 GPa of base oil lubricating to 5.98 GPa of stratified silicate additive lubricating. The results show that a high-hardness self-repair tribo-layer is formed on worn surface, which includes elements of Fe, O, Si, Al, and Mg. It is clear that addition of stratified silicate additive facilitates the formation of high-hardness tribo-layer by action of rubbing, adsorbing, and grinding between tribo-couple. The formation of high-hardness layer could promote wear resistance of tribo-couple.

Based on crystal structure of stratified silicate and analysis of worn surface, self-repair mechanism of stratified silicate additive was suggested. The powder of stratified silicate was secondly refined in running process. The specific surface area of stratified silicate increased rapidly and a large number of nonsaturated bonds were emerged under high-temperature and high-pressure conditions. These nonsaturated bonds adsorbed not only metal ions on worn surface but also metal ions and element C in lubricating oil. Thus, a self-repair layer consisting of FeC_3, Fe_3O_4, and iron magnesium silicate came into being.

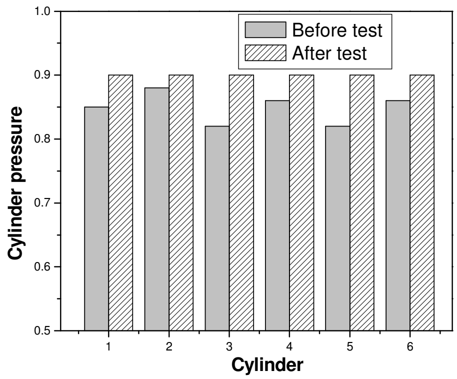
3 Applying test of stratified silicate in vehicle

3.1 Experimental details

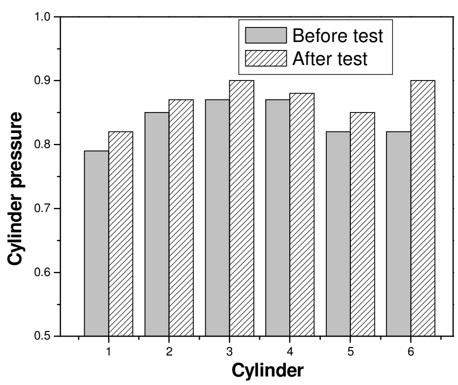
About 0.2 percent by weight of stratified silicate self-repair powder was respectively added into lubricating oil of engine, gearbox, and rear axle differential of two Changjiang 6850 style buses in Qingdao Jiaoyun Group. The actual fuel consumption per 100 kilometer, cylinder pressure, and exhaust emission were measured and averaged after the two buses run for 15, 000 kilometer. The effect of addition of stratified silicate additive would be revealed by comparing with statistical data before addition.

3.2 Results and discussion

Fig. 6 shows the changes of cylinder pressure of the two buses before and after addition of stratified silicate additive. The cylinder pressure of the two buses rose obviously after using stratified silicate and running for 15, 000 kilometer. Cylinder pressure of the first bus rose approximate 6.15 percent and every cylinder pressure is 0.90 MPa after using additive. Besides, cylinder pressure of the second bus rose approximate 3.47 percent. The results testified that stratified silicate self-repair additive could repair worn piston ring and cylinder, and improve seal performance of cylinder. Thus, worn parts can be maintenance and repair under the running and non-disassemble processing conditions.



(a) The first bus



(b) The second bus

Fig. 6 Changes of every cylinder pressure of the two buses

Table 2 Change of exhaust emission of vehicle before and after addition of additive

		The first bus	The second bus
Exhaust emission before addition of additive /ppm	CO	**2.3**	**2.5**
	C_xH_y	**570**	**750**
Exhaust emission after addition of additive /ppm	CO	**1.7**	**1.38**
	C_xH_y	**330**	**300**
Percentage change of exhaust emission	CO	**26.1%**	**44.8%**
	C_xH_y	**42.1%**	**60.0%**

Table 2 shows change of exhaust emission of vehicle before and after addition of additive. Exhaust emission of the two buses was all obviously improved after addition of stratified silicate additive. The CO emission of the first bus decreased as low as 26.1 percent (from 2.3 ppm to 1.7 ppm), and the CH compound emission got a 42.1 percent decrease (from 570 ppm to 330 ppm). For the second bus, the CO emission decreased as low as 44.8 percent (from 2.5 ppm to 1.4 ppm), and the CH compound emission got a 60.0 percent decrease (from 750 ppm to 300 ppm). Engine cylinder pressure increased because of usage of self-repair additive, and higher cylinder pressure could increase the air volume absorbed in each working cycle. The more air volume was absorbed in engine cylinder, the more sufficient combustion of oil could be obtained for the same spraying oil. Besides, the increase of sealing performance decreased consumption of lubricating oil and emissions of CO and CH compounds.

Table 3 Actual fuel consumption of vehicle before and after addition of additive

Vehicle	The first bus				The second bus			
Month	5	6	7	8	5	6	7	8
Total kilometers /km	**6208.2**	**6603.8**	**6904.6**	**6671.4**	**2980.6**	**6127.9**	**6744.2**	**6460.2**
Total fuel consumption /L	**1625**	**1640**	**1639**	**1627**	**860**	**1625**	**1828**	**1786**
actual fuel consumption per 100 km/L	**26.18**	**24.38**	**23.74**	**24.38**	**28.85**	**26.52**	**27.10**	**27.64**
Percentage change of fuel consumption per 100 km *	**0**	**- 5.1%**	**- 9.3%**	**- 6.9%**	**0**	**- 8.1%**	**- 6.1%**	**- 4.2%**

Note: * The fuel consumption per 100 kilometer in May was defined as the baseline.

Table 3 shows the actual fuel consumption of vehicle before and after addition of additive. The fuel consumption per 100 kilometer in May (without addition of stratified silicate additive) was defined as the baseline. The results show that the fuel consumption per 100 kilometer every vehicle decreased obviously after usage of self-repair material in June, July, and August. One reason was that seal sealing performance of piston ring and cylinder were improved, which could increase combustion efficiency. The other reason was that the smoother self-repair layer on worn surface decreased power loss caused by friction.

4 Conclusions

The conclusion could be drawn from analylzing the tribological properties and application in bus of stratified silicate.

(1) The worn surface was polished and surface roughness would be decreased by addition of stratified silicate additive in base oil, which resulted in improving of lubricating status and decrease of friction in sliding process.

(2) A large number of nonsaturated bonds were formed from stratified silicate self-repair material under high-temperature and high-pressure conditions. A high-hardness self-repair layer came into being by nonsaturated bonds adsorbing and reacting with metal elements and element C of worn surface and lubricating oil. This tribo-layer could improve wear resistance of tribo-couple and prolong service time of equipments.

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