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Evaluation of ring surfaces with several coatings for friction, wear and scuffing life

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Abstract: Friction and wear of the sliding components in an automobile cause an increase in both fuel consumption and emission. Many engine components involved with sliding contact are all susceptible to scuffing failure at some points during their operating period. Therefore, it is important to evaluate the effects of various surface coatings on the tribological characteristics of the piston ring and cylinder block surface of a diesel engine. Wear and scuffing tests were conducted using a friction and wear measurement of the piston ring and cylinder block in a low friction diesel engine. The frictional forces, wear amounts and cycles to scuffing in the boundary lubricated sliding condition were measured using the reciprocating wear tester. The tester used a piece of the cylinder block as the reciprocating specimen and a segment of the piston ring material as the fixed pin. Several coatings on the ring specimen were used, such as DLC, TiN, Cr-ceramic and TiAlN, in order to improve the tribological characteristics of the ring. The coefficients of friction were monitored during the tests, and the wear volumes of the piston ring surfaces with various coatings were compared. Test results show that the DLC coating exhibits better tribological properties than the other coatings. The graphite structure of this coating is responsible for the low friction and wear of the DLC film. The TiN and DLC coatings show better scuffing resistance than the other coatings. The TiN and Cr-ceramic coated rings show good wear resistance and high friction.

Key words: coated ring; friction and wear; scuffing; diesel engine

1 Introduction

The friction and wear in automobile components increase both fuel consumption and emission. It was reported that frictional loss was responsible for about 25% of the overall fuel consumption in engines[1−3]. Most of the frictional loss occurs on the sliding surface between the piston ring and cylinder block in the engine [4−6]. The sliding surfaces of components in an engine should be investigated for their tribology to develop a low friction diesel engine. Many factors are related to the friction and wear behavior of lubricated sliding surfaces, including the mechanical properties, sliding environments, chemical properties and surface properties [6]. Several alternative technologies have been explored in order to achieve low friction and the necessary wear resistance. One potential solution that is currently being investigated is the deposition of coatings with low friction and wear-resistance on piston rings. Ceramic coatings can increase the life of sliding components due to their outstanding low friction characteristics and good wear resistance[7−8]. Scuffing is a tribological failure described as a sudden catastrophic failure of the lubricated sliding surface, which is characterized by a sudden rise in friction, contact temperature, vibration and noise, resulting in a surface roughening through severe plastic flow and loss of surface integrity[9−10].

Many engine components involved with sliding contacts are all susceptible to scuffing failure at some points during their operating period.

In this study, the effect of various surface coatings on the tribological characteristics of the piston ring and cylinder block surfaces of a diesel engine was evaluated. Ceramic coatings such as TiN, TiAlN, Cr-ceramic, and DLC, were applied to piston ring specimens. Friction forces, wear amounts, and time to scuffing failure were evaluated using the reciprocating tribometer.

2 Experimental

The reciprocating wear tester was used for the

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lubricated sliding tests[11]. The ring specimen was cut from the commercial diesel engine and fixed onto load cells to measure the normal load and the friction force. Fig.1 shows the schematic drawing of the reciprocating wear tester. The size of the specimens of cylinder block used for the test was 4 mm ×4 mm×60 mm, and that of the piston ring used for the test was 1.5 mm×2.5 mm×3.5 mm.

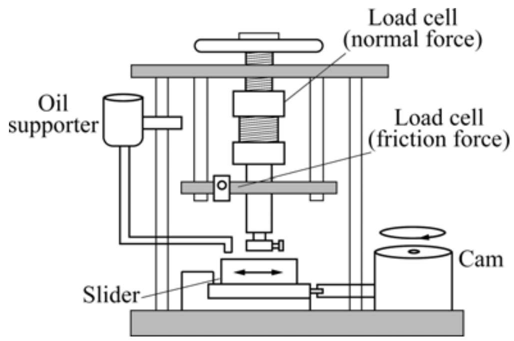

Fig.1 Schematic drawing of reciprocating wear tester

The ring material was ductile cast iron and the block specimen, which was made of grey cast iron with a hardness of about HV 270, was held on the reciprocating table in an oil bath.

Cylinder block specimens were ground to have the surface roughness of about 0.7 μm in R_a. Several coatings were applied on the ring surface, such as TiN, TiAlN, and DLC. Those coatings were compared with the conventionally used Cr-ceramic coating. The coated surfaces had hardness in the range of HV700−800.

The lubricated sliding tests were carried out in a repeated-pass reciprocating motion under a stroke of 50 mm and a frequency of 2 Hz. The normal load was fixed at 500 N during the tests to measure both the friction and wear, and each test lasted for 2 h. In the scuffing tests, the load was increased from 300 N by a step size of 200 N at every 30 min interval until scuffing occurred. Scuffing was defined as a sudden increase in friction [10].

SAE5W40 engine oil was used as a lubricant during testing. The friction coefficients were averaged by using the absolute values during a cycle of test and the wear volumes were measured from the changes of the surface geometries after testing.

3 Results and discussion

The lubricated sliding tests were performed on the surfaces of engine block and piston ring to evaluate the effect of surface coatings on the friction and wear. Fig.2 shows the wear amount of the cylinder block specimens and the corresponding coefficients of friction. The wear volume of the cylinder tested against the TiAlN coated ring is the largest among the tested coatings, while the DLC coating experiences the lowest wear volume. The friction is also the lowest in the case of the DLC coating. This low value of friction is one of the reasons for the low wear volume with this coating. DLC film can be used to reduce the friction by more than 20% compared with the Cr-coating. SEM images and EDX analyses on ring specimens are shown in Fig.3. TiN and TiAlN represent some plastic deformation on the sliding surfaces. The Cr-ceramic coating shows some marks of adhesion and surface cracks. Oxygen is very rich on surfaces and the presence of oxygen may cause the formation of the chromium oxide.

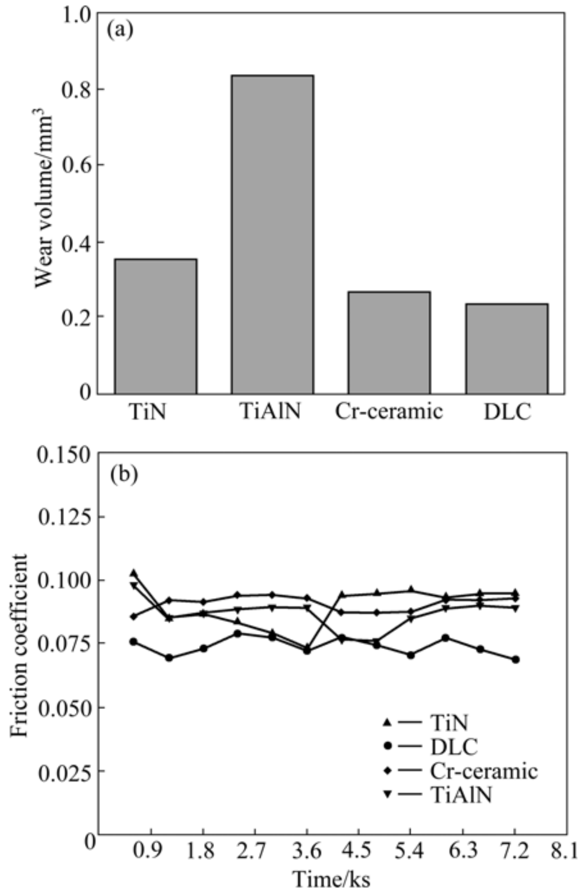

Fig.2 Wear volumes (a) and friction coefficients (b) of cylinder blocks with different coatings

The sliding surface of the DLC film is very smooth and mild wear is dominant on the surface. The EDX analysis indicates that the metallic components of the Fe transferred from the cylinder block are detected on the worn ring surfaces of the TiN, TiAlN and Cr-ceramic coatings. However, there is almost nothing transferred to the DLC surface from the cylinder. The components transferred are caused by adhesion between the two surfaces, which increases the friction and wear of the materials. It is therefore evident that adhesion is not dominant in the case of DLC.

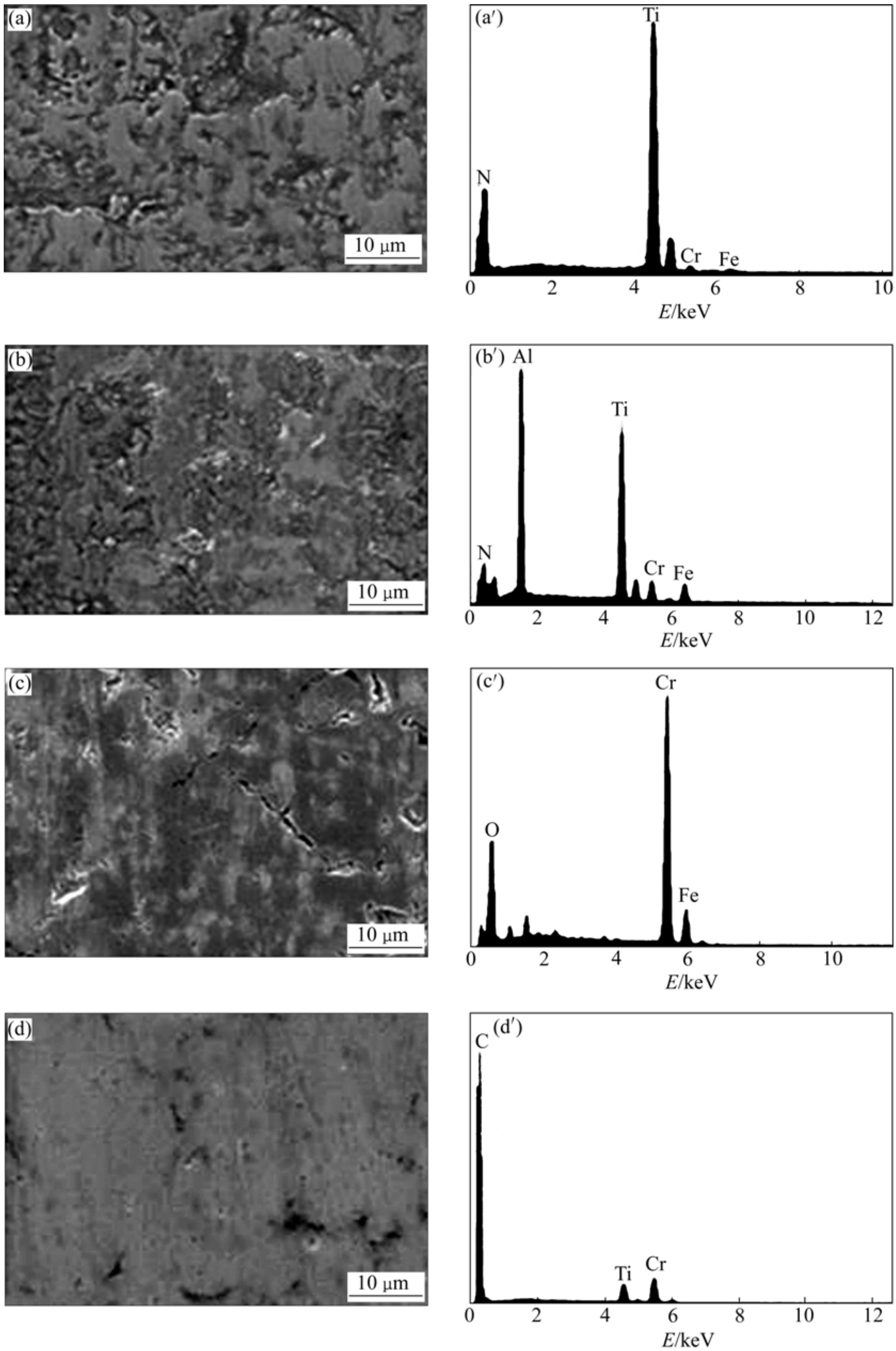

Fig.3 SEM images and EDX spectra of worn ring specimens with coatings: (a), (a′) TiN; (b), (b′) TiAlN; (c), (c′) Cr-ceramic; (d), (d′) DLC

The Raman spectrum was used to verify the low friction of the DLC film as shown in Fig.4. The G peak of the worn surface moves to a higher wave number than that of the unworn surface. Also, the intensity of the D peak is stronger than that before wear. This allows us to conclude that there is graphitization on the DLC film,

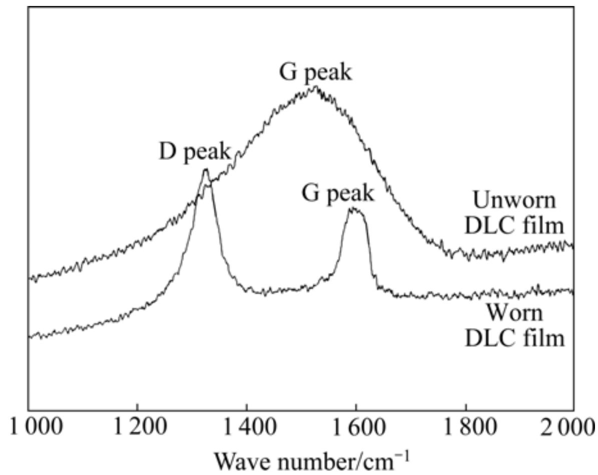

Fig.4 Raman graph of worn and unworn ring specimens with DLC coatings

meaning that the ratio of the sp^3 to sp^2 bonded carbon configuration of the DLC film decreases during the reciprocating test[12]. The graphite structure is responsible for the low friction and wear of the DLC film.

Scuffing tests were performed with the cylinder block against the coated ring specimens. There is a rapid increase in friction at the onset of scuffing. During these tests, the loads were increased from 300 N by a step size of 200 N up to the point of scuffing.

The test was performed for a period of 30 min for each load. The surfaces containing Cr-ceramic and TiAlN represent the shorter scuffing life among all the surfaces, as shown in Fig.5. The surfaces are broken-in differently in order to adapt the surface interactions as the load is increased from 300 N. There is no scuffing up to 1 900 N for the cases of TiN and DLC. The DLC coating represents the lowest value of friction among all of the coatings.

The scuffed surfaces of both the Cr-ceramic and TiAlN show severely adhesive damage on their surfaces, as shown in Fig.6. There are some marks of adhesive wear in the case of the TiN coated ring, even though there is no scuffing up to 1 900 N. The siding surface of the TiN coated ring appears to be damaged due to the severe interactions. However, there are only some mild scratches on the DLC coated surface. The dominant wear mechanism of sliding against DLC film is classified as only mild abrasive wear, not adhesive wear.

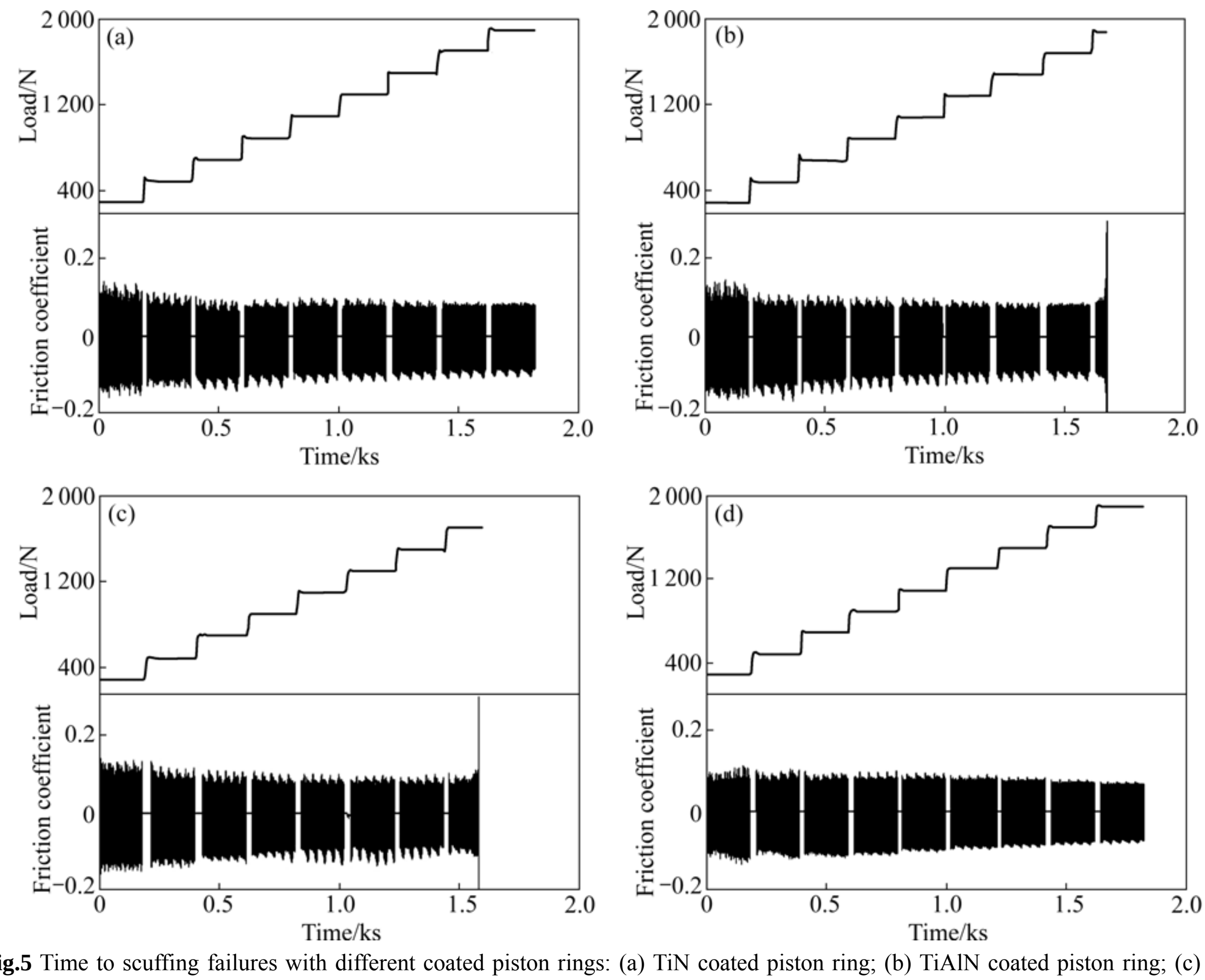

Fig.5 Time to scuffing failures with different coated piston rings: (a) TiN coated piston ring; (b) TiAlN coated piston ring; (c) Cr-ceramic coated piston ring; (d) DLC coated piston ring

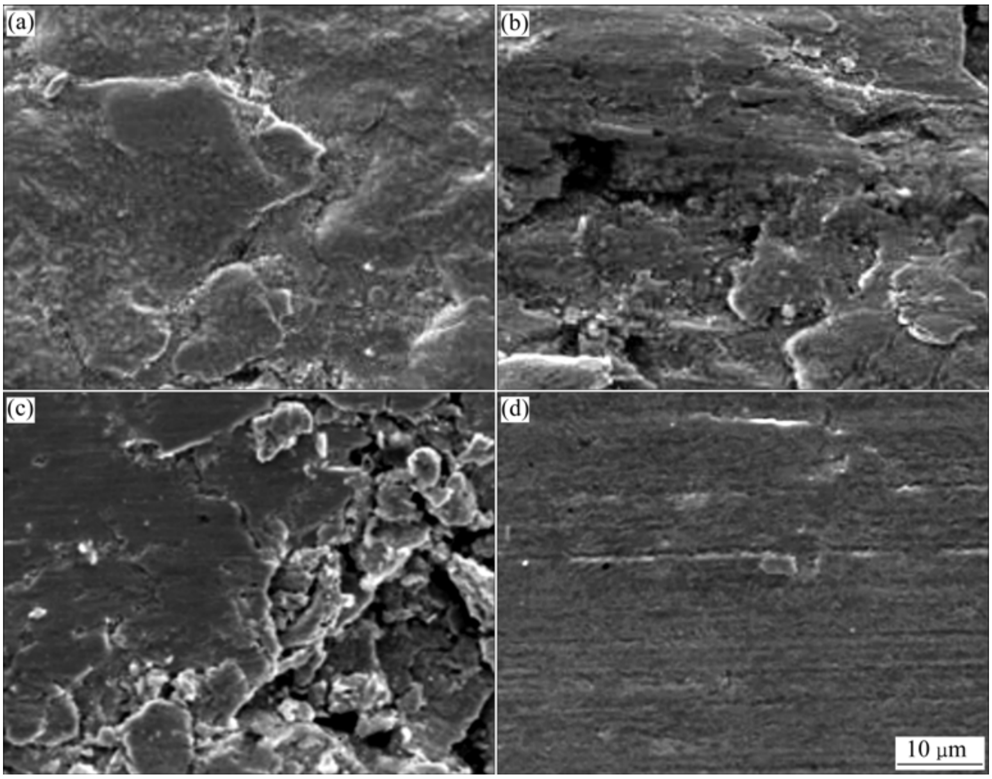

Fig.6 SEM images of worn cylinder specimens after scuffing tests: (a) TiN coating; (b) TiAlN coating; (c) Cr-ceramic coating; (d) DLC coating

4 Conclusions

1) Wear and scuffing analysis between the cylinder block and piston ring specimens during the lubricated sliding tests was carried out in a repeated-pass reciprocating motion during the lubricated sliding tests in order to investigate the effects of surface coatings on friction. Cr-ceramic, TiN and DLC coated rings exhibit good wear resistance.

2) The amount of wear and the coefficient of friction of the coatings are the least for the DLC coating, which can be attributed to the process of graphitization on the DLC film. The graphite structure is responsible for the low friction and wear of the DLC film. TiN and DLC coatings show better scuffing resistances than the other coatings, while DLC coating represents only mild abrasive wear that prolongs the time to scuffing failure.

References

[1] RYK G, KLIGERMAN Y, ETSION I, SHINKARENKO A. Experimental investigation of partial laser surface texturing for piston-ring friction reduction [J]. Tribology Transactions, 2005, 38: 583−588.

[2] PRIEST M, TAYLOR C M. Automobile engine tribology-approaching the surface [J]. Wear, 2000, 241: 193−203.

[3] TAKIGUCHI M, MACHIDA K, FURUHAMA S. Piston friction force of a small high speed gasoline engine [J]. ASME J Tribology, 1988, 110: 112−118.

[4] TUNG S C, McMILLAN M L. Automotive tribology overview of current advances and challenges for the future [J]. Tribology International, 2004, 37: 517−536.

[5] TRUHAN J, QU J, BLAU P. A rig test to measure friction and wear of heavy duty diesel engine piston rings and cylinder liners using realistic lubricants [J]. Tribology International, 2005, 38: 211−218.

[6] RABINOWICZ E. Friction and wear of materials [M]. New York: Wiley-Inter Science, 1995: 14−28.

[7] HOLMBERG K, MATTHEWS A. Coatings tribology [M]. Amsterdan: Elsevier, 1994: 172−189.

[8] BHUSHAN B, GUPTA B K. Handbook of tribology [M]. New York: McGraw-Hill, 1991

[9] AJAYI O O, HERSGERGER J G, ZHANG J, YOON H, FENSKE G. Microstructural evolution during scuffing of hardened 4340 steel—Implication for scuffing mechanism [J]. Tribology International, 2005, 38: 277−282.

[10] LEE Y Z, LUDEMA K C. The shared-load wear model in lubricated sliding: Scuffing criteria and wear coefficients [J]. Wear, 1990, 138: 13−22.

[11] AHN T S, CHO D H, LEE Y Z. Evaluation of friction force, wear volume and scuffing life of piston rings and cylinder blocks with different surface roughness for low friction diesel engine [J]. Key Engineering Materials, 2007, 345/346: 713−716.

[12] QGWU A, LAMBERTON R W. Characterisation of thermally annealed diamond like carbon(DLC) and silicon modified DLC films by Raman spectroscopy [J]. Physica B, 1999, 269: 335−344.

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