Advanced Tribological Coatings for Automotive Applications

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ABSTRACT
Coatings have special and very important role in automotive applications. To reduce energy consumption and wear, advanced nano-composite MeN-X type tribological coatings promises very challenging solutions. Nano-composite coatings of MeN-X type (for instance nanosized MoN) surrounded by a soft metal (such as copper, silver, tin) exhibited high hardness over 40 GPa, low fricition coefficient and negligible wear against steel, alumina and aluminium
Key-words: nano-composite coatings, friction and wear, molydenum nitride,

INTRODUCTION

In year 2000 about 180 million passenger cars, 25 million commercial vehicles (8 million heavy commercial vehicles) and over 500 000 coaches and buses have been on roads in EU (1-2). By 2010, it is estimated that the demand for mobility will increase 24% for passenger cars and 38% for freight vehicles (1-3).

The energy consumed for all the transportation activities adds up to approximately 30% of the total energy consumption in the EU; all of which relies on fossil fuels. The energy consumed and the emission of polluting gases created through all these activities are a major concern for the world's future. Hence car makers are forced to produce more energy efficient and environmentally friendlier vehicles (3).

Approaches to achieve these aims can be summarized as follows:

1. More efficient after treatment of exhaust gases
2. Introduction of advanced fuel direct injection (common rail, multi injection) and engine management systems
3. Use of alternative fuels such as natural gas and hydrogen.
4. Reduction of the overall weight of the vehicle, by using lighter materials in the body work and engine
5. Reduce the energy losses and wear

For the realization of all the above mentioned issues improved or new materials and surface treatments fulfilling these demands are required.

In this presentation an overview of plasma based surface treatments for improving the tribological properties of the engine components with special emphasis on possible applications of nano-composite coatings will be given.

REDUCTION OF FRICTIONAL LOSSES BY SURFACE TREATMENTS

In the engine and engine components power losses due to friction adds up to 15% of the total energy losses in a vehicle (4). Most of the friction related power losses occur at the cylinder liner/ piston-piston rings. Crank train, valve train and injection pumps are the other components which contribute to these losses (Figure 1).

Presently Physical Vapor Deposition (PVD), Plasma Assisted Chemical Vapor Deposition (PACVD) based coatings are being applied to some extent to engine components for combating frictional losses.

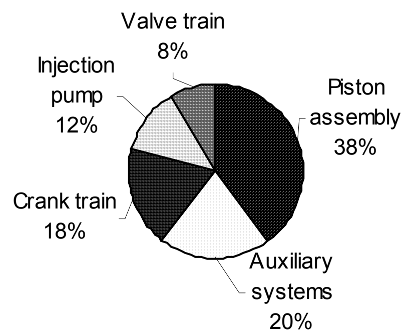


Figure 1: The distribution of frictional losses in IC engines (7)

CYLINDER LINER/ PISTON –PISTON RINGS

For the production of engine blocks cast iron is the most commonly used material. In order to reduce weight aluminum alloy engine blocks is introduced. In these engine blocks, due to the mechanical and tribological limitations a cylinder liner of cast iron is used. To improve the performance of the piston and piston rings working against cast iron liners several coatings such hard chrome plating, thermal and plasma sprayed coatings is widely applied.

Challenges in this system are:

-to use totally aluminum engine blocks with or without aluminum liner. In order to achieve this aim, several plasma spray, PVD based coatings and laser based surface modifications are suggested and tested(5,6).

-to develop suitable surface coatings with thermal barrier properties to be able to increase the operating temperature of the engine. Several plasma based coatings are suggested.

-to develop piston rings that can withstand higher pressure contact and give a low coefficient of friction that is needed to ensure an increase in compression ratio, hence improve the quality of combustion.

Presently, industrially accepted PVD coatings in piston assembly are (7):
-30 micrometer thick CA-PVD CrN coatings started to be applied on piston rings.
-Diamond like carbon (DLC) or Me doped DLC coated piston pins produced by PACVD

VALVE TRAIN

Valve train is another source for frictional losses especially at low speed range where boundary lubrication conditions prevail. Presently rocker arms and tappets of this system are coated with DLC and CrN.

The challenges in these system are:

to develop tribological coatings that can perform better at the cam/follower interface and cam nose

-to lower the weight of valves by replacing the steel valves with light alloys, such as titanium, aluminum or intermetallics and to develop tribological surface treatments for these materials.

INJECTION PUMPS

Me doped DLC, DLC and CrN has been successfully applied to diesel engine pumps parts such as injector and plunger. However, there is a need for the development of new surface treatments and materials which can withstand better under the extreme conditions developing in common rail and direct injectors.

GEARS

Surface hardened materials are used in the manufacturing of gears. Conventionally the surfaces of these materials are hardened by carburizing and nitriding. PVD coatings are started to be applied on gears in order to improve surface hardness, surface roughness, friction coefficient and oil wettability. The coatings used for this purpose are B_4C, WC-C:H and CrN (8).

NANOCOMPOSITE COATING APPROACH TO REDUCE WEAR AND FRICTION

MeN-X type nanocomposite structures are composed of immiscible metal nitrides and soft metals such as copper and silver. This concept is first introduced by Musil and co-workers (9). Introduction of the X phase into the structure results in a nanocrytalline structure composed of nano sized MeN matrix surrounded by the soft metal

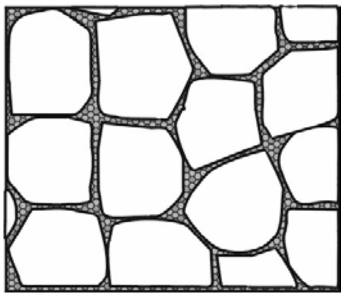


Figure 2. Schematic structure of MeN-X type nanocomposites

By the introduction of the second phase up to 1-2 at% a substantial increase in hardness and change from columnar to equiaxed grain structure is achieved (10). Further increase of the “X” concentration results in both decrease of the grain size and hardness.

From tribological point of view these structures opens new horizons.

It is possible to increase the lubricity of a hard coating by introducing a soft metal into the structure or add metals into the structure that can form lubricious films by interacting with the components of the oils.

Both of these approaches are laboratory tested within the scope of a joint study conducted in ITU Metallurgical and Materials Engineering Department, Surface Technologies Group and Argonne National Laboratories, Tribology Division.

TRIBOLOGICAL PERFORMANCE OF MoN-Ag AND MoN-Cu COATINGS

MoN is selected as the MeN phase because of its higher hardness compared to other nitrides such as TiN, CrN, ZrN and better tribological properties (11-13). Ag and Cu are selected as “X” phase by taking into consideration the possibility of formation of lubricious oxides or molybdates of molybdenum-copper and silver (14-16) and also the possibility of the diffusion of the soft metal to the contact area with increased temperature due to friction (17).Moreover silver is a well known high temperature solid lubricant (16).
The expected reflections of structural changes induced by Ag and Cu additions can be mechanical and/or tribochemical. Conversion of the columnar structure into fibrous- equiaxed may result in better resistance to cyclic loading (fatique). The high possibility of the formation of lubricious oxides of Mo-Cu-Ag at the contact zone during wear can have a positive effect on tribological behavior.

In order to see the role of tribo films and structure on tribological behavior a series of reciprocating wear tests under severe conditions are conducted on MoN, MoN-Cu and MoN-Ag coatings. The coatings are produced by hybrid CA-PVD based technique (18). Molybdenum plasma is formed by CA-PVD and the soft metal is introduced into the coating by magnetron sputtering.

Introduction of copper and silver increased the hardness up to 1-2 at% concentration. Further increase resulted in a decrease of hardness as expected (Figure 3). For reference a CAPVD TiN coated sample (HSS substrate, 2.5 micron thickness, with a hardness of 30 GPa) is also tested under the same conditions.

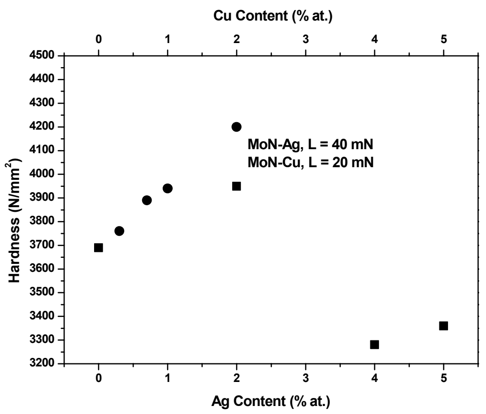
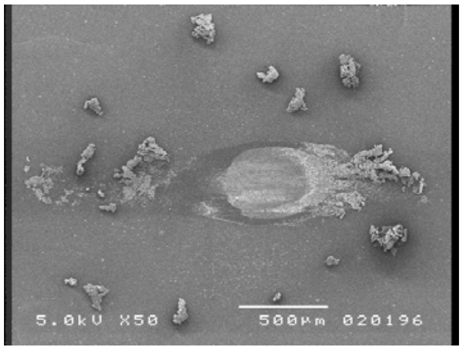
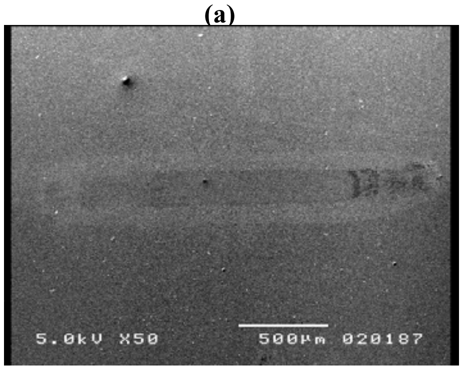


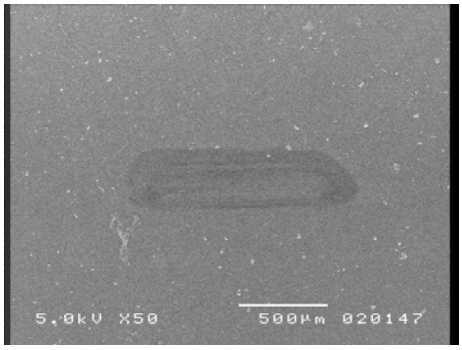
Figure 3. The relationship between hardness and Cu-Ag contents of the MoN films.



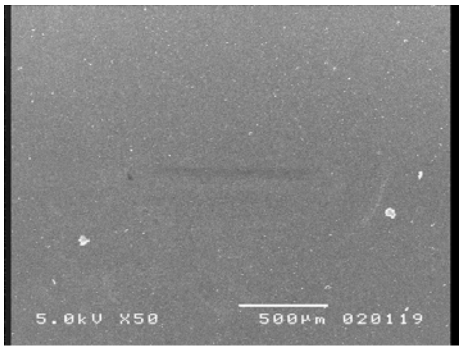
(a)



(b)



(c)



(d)

Figure 5: SEM images of wear scars after reciprocating tests a) TiN coating, b) MoN coating c) MoN-2at%Cu coating d) MoN-5%Ag coating

TiN coatings under the severe test conditions utilized showed a very poor performance, the coating is totally degraded in the first few thousand cycles. MoN coatings showed a far better performance compared to TiN; they gave a lower friction coefficient of 0.45 and a slight wear depth of about half a micrometer. The addition of copper and silver resulted in further lowering of COF to around 0.3 and almost no wear depths are observed in the wear scars (Fig 4 a-d).

Another positive effect of Cu and Ag is observed on the wear volumes of the alumina balls. The wear volumes of balls decreased 2-3 fold with the addition of Cu and Ag. The width of the wear tracks on MoN-5at%Ag coating was the narrowest of all the coatings indicating minimum wear on balls

These results showed the important role of tribofilms on wear behavior. TiN with a hardness of 30 GPa could not resist the severe conditions. However MoN which is known to form lubricious molybdenum oxides performed satisfactorily. By the addition of copper to the coating wear performance became better indicating better lubricating properties of molydenum-copper oxides (molybdates) . In the case of 5 at% silver addition further improvement is achieved in the wear performance. Although this coating had a lower hardness of 33 GPa compared to all Mo-N-Ag-Cu series of coatings it gave the best performance showing the more dominant role of tribofilms on wear.

These results indicated that these coatings can be used for improving the tribological behaviour under fretting, and galling conditions.

These coatings also exhibit extremely low friction coefficients (as low as 0.05) under boundary lubricated sliding conditions and can be applied on a variety of materials. Moreover no appreciable wear is detected both on the coating and the steel pins.

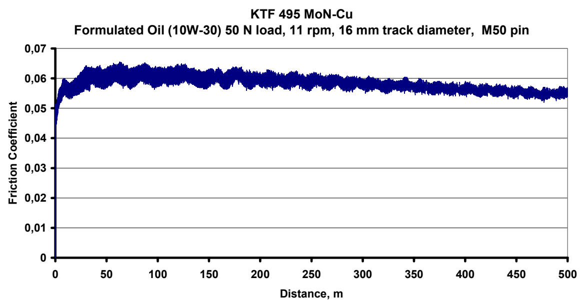


Figure 6. COF-distance behavior of MoN-Cu nanocomposite coatings under boundary lubrication conditions

Preliminary experiments conducted on another version of MoN-X (MoN-Sn) coatings against Al-Si alloy pins gave very promising results(Figure 7).

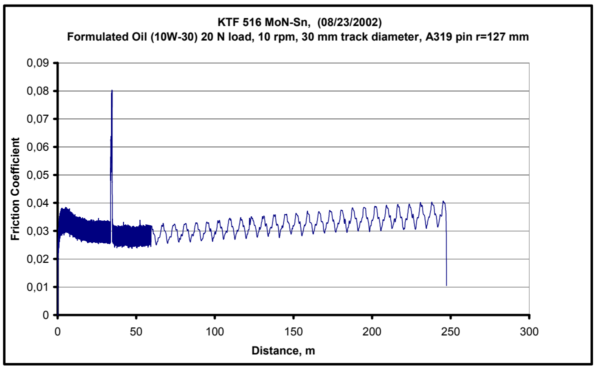


Figure 6. COF-distance behavior of MoN-Sn nanocomposite coatings under boundary lubrication conditions against Al-Si alloy pins.

The unique chemical compositions of the coatings enable them to synergistically interact with the environment and lubricant additive packages to achieve low friction coefficients under boundary lubrication regimes – a feature that translates into direct energy savings and improved durability/reliability.

CONCLUSION

Nanocomposite coatings composed of a hard metal nitride-carbide or carbonitride and a soft metal has a big potential for solving tribological problems in the automotive industry. These coatings can be tailored according to the demands.

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