Low Friction Coating Technology for Mobility- Recent and Future Solutions

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1. Introduction

The world makes efforts for transition of eco-friendly mobility to achieve the goals of carbon gas emission reduction for mitigating global warming. EU has a goal of this reduction by 55% by 2030 compared to 2021, and as of October 2021, a total of 55 countries have declared carbon neutrality, so environmental regulations are expected to be tightened. Hyundai Motor Group also aims to produce 1.51 million electric vehicles (EV) domestically and 3.64 million globally by 2030.

EV has 15-25 KWh per 100 km, 4 kg CO_2 emission and 6-10 US$, compared to gasoline 57 KWh, 14 kg CO_2 and 10 US$. Also, automotive's tribology, friction and wear is changed. EV consists of less moving parts than gasoline, but these are severely loaded by high temperature and electrical loading caused by high torque and speed. Therefore, these shall be protected with high corrosion and oxidation resistance. EV's friction is mostly boundary and mixed lubrication, compared to ICE with hydrodynamic lubrication. Electrical surface failures are e.g. clustering, frosting, fluting, crater, white etching, discolored grease, current marks, gear fluting and microbubbles. Microbubbles are formed by friction under electrical condition and at subsurface formed, grown and exploded. Recently modified friction test for EV parts is, e.g. ball on disk (1 m/s, 50 N, 1.1 GPa, 80 V, 12.5 kHz). Moreover, it is reported that for the protection of wear and friction of EV application, the coatings are considered, e.g. DLC, CrN and CrCuN [1].

Fig. 1 shows overview - automotive coatings (parts) and Fig. 2 overview - automotive coatings (dies, tools), which are previously and recently developed surface technologies for wear protection and fuel economy [2]. Engine and transmission parts are coated with CrN, DLC and SiO-DLC. High temperature engine parts are coated with TiAlCrSiCN and wet friction with nano diamond PTFE. Forming dies of advanced high strength steel (AHSS) are coated with TiAlCrCN, AlTiCrN+MoS_2. And Al die casting die is coated with TiAlCrSiCN. DLC (Diamond-Like Carbon) is applied for tappets with performance of friction reduction of 40%, resulting increase of fuel efficiency 0.8%. To enhance the DLC's demerits (humidity weakening, only 250 ℃ thermal stability), SiO doped DLC is developed. For instance, high pressure injector balls (Fig. 3) are SiO-DLC coated with PVD and PACVD for impact resistance and durability [3]. Recently, ZrCuSiN is developed with the design concept of hard ZrN and soft Cu, Si mixture. Furthermore, ta-C is applied for piston ring as next generation of DLC.

Fig. 1 Overview - automotive coatings (parts)

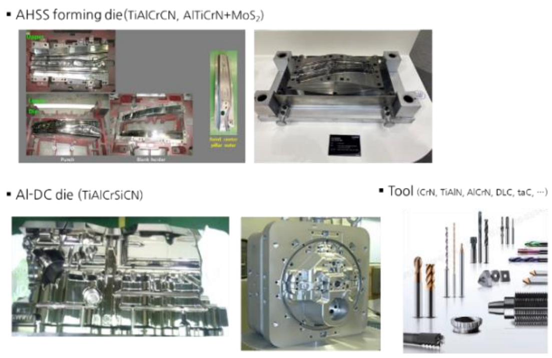

Fig. 2 Overview - automotive coatings (dies, tools)

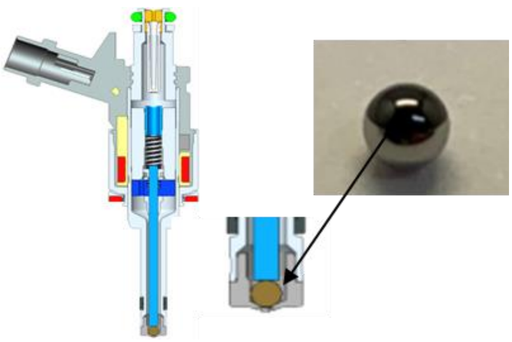

Fig. 3 High pressure injector balls (SiO-DLC coated)

2. Global R&D status of coating technology

Global coating companies, e.g. Balzers, Ionbond, Hauzer and Platit, recently developed with the keywords, hybrid process, high ionization, low temperature process for polymer and seal coating. Ionbond with arc and sputtering, Balzers Milubia with ta-C for polymer shaft and seal), Baliq carbos with HIPIMS and CVD for CFRP cutting tool, PVD radiator grill, Platit LACS of arc and sputter, Platit ta-C with DCMS and HIPIMS or SCIL, Hybrid with PVD, PACVD and FLAD.

Fraunhofer IWS has 'CHEPHREN' project (ultra-smooth, super-lubricating taC), Diamor project (taC in oil free environments) and MoS_2-taC, high temperature resistant ta-C-X (Si, B, Cr, Mo, Fe). RWTH Aachen-IOT, Germany, has also Chephren project and developes, e.g. CrAlN on PA12, PEEK, Dry lubrication of gears with (Cr,Al)N+Mo:S and (Cr,Al)N+Mo:W:S.

Recent ICMCTF conferences [4, 5] showed R&D trends in modern coating techniques. Coating trends are changed for wider application and extreme environments with the keywords: polymer and plastic coating, seals coating, taC, low temperature coating process, elements (Zr, Nb, Hf, Ta, V, Y, B).

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Carbon based or low friction coatings are presented, e.g. ta-C for over 500℃ application (Bosch), Seals DLC (Balzers), DLC with Graphene Nanoplatelets (Uni. Leeds, SKF), Anti-Friction Ti-DLC (KIMS, Uni. Nagoya), Conductive a-C:H:N (UniUpper Austria, Rubig), taC for Plastic (Fraunhofer IWS, Von Ardenne), CrAlMoCuN, (Cr,Al)N-Mo:W:S (RWTH Aachen).

Other coatings with multi-elements are: TiZrNbTaFeBN (N.-Uni. Taiwan), (Ti,V,Zr,Nb,Hf,Ta)N (Aachen, Uppsala, Plansee), W-S-(C); Nb–V–N (Uni. Coimbra), TiN-Nb Multilayers (TU Wien, Oerlikon, Plansee), VAlN+O (RWTH Aachen, Uppsala Uni.), TaB_X (Linköping Uni, Plansee), Cu_xO-MoS_2 (Uni Coimbra), TiZrN or TiZrCN (Mitsubishi Materials).

3. New coating project

In Korea, KIMS (Korea Institute of Materials Science) and KITECH (Korea Institute of Industrial Technology) with universities (Gacheon, Hanyang, Gyungbook) and coating companies and Hyundai Motor Group collaborate for the longterm project for the development of ultralow friction coatings for moving parts incl. EV application [6]. The partners are responsible for the coating design, equipment, process (KIMS), coating design, target elements, coating materials (KITECH), friction and wear testing technique (Gacheon Univ.), coating structure, interface (Hanyang Univ.), simulation, prediction (Gyungbook Univ). Current level of DLC related coatings like DLC, SiO-DLC and ta-C have the friction coefficient (CoF) of 0.05, pin on disk with oil base. To enhance to CoF of 0.03 and further 0.01 (ultralow friction), new project started. First candidates of CoF 0.03 are Metal doped ta-C, DLC related+MoS_2 like Zr-DLC, Zr-taC, (SiO)-DLC-MoS_2. Final target is CoF of 0.01, Zr- and Mo-Nanocomposite (+MoS_2) like ZrSiC, MoZrTiSiN, ZrAlCoMoCuN and ZrMoTiCuSiN.

4. Conclusion

EV's friction is mostly boundary and mixed lubrication, compared to ICE with hydrodynamic lubrication, i.e. more severe. Engine and transmission parts coated are with CrN, DLC, SiO-DLC, taC and ZrCuSiN. High temperature engine parts are coated with TiAlCrSiCN and dies with TiAlCrCN, AlTiCrN+MoS_2 and TiAlCrSiCN. Globally, coating companies developed with the keywords, hybrid process, high ionization, low temperature process for polymer and seal coating. According to ICMCTF conferences, coating trends are changed for wider application and extreme environments with the keywords: polymer and plastic coating, seals coating, taC, low temperature coating process, elements (Zr, Nb, Hf, Ta, V, Y, B). In Korea, KIMS and KITECH with many partners collaborate for the long-term project for the development of ultralow friction coatings for moving parts of EV application. To enhance to friction coefficient of 0.03 and 0.01 for ultralow friction, various coatings are to consider. Metal doped ta-C, DLC related+MoS_2, Zr- and Mo-based nanocomposites.

Reference

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