Tribological Properties of Duplex Surface Treatment for Dies for Plastic Processes

Yoshitsugu Kimura
Kagawa University
1-0 Saiwai-cho, Takamatsu, 760-8521 Japan

The duplex treatment comprises coating a hard layer onto a nitrided steel substrate. Because of their superb tribological properties, TiN-duplex-treatments are expected to be a promising surface treatment to improve the performance of tools and dies, which are to be used in unlubricated plasticity processes of aluminum alloy.

A series of ring-on-block dry sliding experiments are conducted with a TiN-duplex-treated tool steel against an aluminum alloy, in which the substrate is tempered to different hardness to evaluate its effectiveness.

A 0.4C-5.1Cr-1.4Mo-0.9V-1.0Si alloy tool steel was used as the substrate for the block specimens throughout the experiments. Plasma bright nitriding of its sliding surface was made at 750K to form a nitrided layer of 50μm thickness. Then the blocks were tempered in hydrogen atmosphere for different time durations, 0.5, 2 and 4 hours. Finally, a TiN film of 2.5μm thickness was coated on each surface by a hollow cathode discharge method at 720K. They were named like DM-x-y, where DM stands for the duplex treatment, x is the approximate thickness of the TiN coating film in micrometer, and y is the duration of the tempering of the nitrided layer in hour. For comparison, the same steel block with the same nitrided layer but without TiN coating film, PN-0, was used. The ring specimens were made of a 0.42Si-0.18Fe-0.01Cu-0.01Mn-0.50 Mg-0.01Cr-0.01Zn-0.01Ti aluminum alloy.

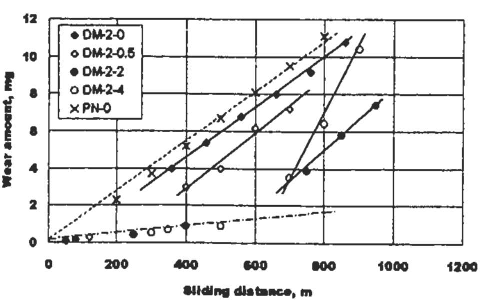

Fig.1 Increase in wear with sliding distance

Sliding experiments were conducted on a ring-on-block tribometer under a load of 250N at a sliding speed of 0.1m/s without intentional lubrication. The atmosphere was laboratory air; temperature was 288-298K and relative humidity was 45-60%. Wear was determined with block specimens by weighing after a run.

The increase in wear of the block specimens with sliding distance is shown in Fig.1. Wear of DM specimens occurred in two successive stages: the first stage having a low wear rate and the second stage having a high wear rate. Although wear was not perfectly uniform over a scar, the first stage is characterized by wear of the TiN coating film, and all DM specimens show an identical low specific wear rate of 1.5 $\times 10^{-6}$mm^3/Nm. The wear rate is much higher in the second stage and markedly differs depending on the tempering duration. The specimen without coating film PN-0 shows a linear increase of wear from the outset of sliding, with a relatively high specific wear rate of 6.9$\times 10^{-6}$mm^3/Nm.

The film life is defined by the sliding distance at which the amount of wear of the block specimens exceeds 2.7mg, the total mass of the TiN coating film in a wear scar, which is read from Fig.1 on the extrapolated distance-wear line for the second stage.

The specific wear rate and the film life thus determined are summarized in Table 1.

Table 1 Wear and film life

Specimens	Specific wear rate, 10^{-6}mm^3/Nm		Film life, m
	Film	Substrate	
DM-2-0	1.5	7.0	270
DM-2-0.5	1.5	7.2	370
DM-2-2	1.5	9.0	670
DM-2-4	1.5	17.5	680
PN-0	—	6.9	—

It is evident that the coating of TiN markedly reduces the wear of the blocks. Further, the tempering of the nitrided substrate layer improves the life of the TiN coating film of DM specimens, and, in particular, the specimens tempered for more than two hours show prolonged film life which amounts more than twice of that of DM specimen without tempering.

Observation of wearing surfaces by SEM revealed two operating mechanisms of wear. One is small-scale, shell-like chipping, which is observed commonly with DM specimens, and the other is scratching that leads to larger-scale exposure of the substrate. The scratching starts from small surface cracks vertical to the sliding direction, and is followed by the propagation of nearly horizontal cracks at the TiN-substrate interface. Detached hard TiN fragments then severely scratch the coating film and the substrate. It is concluded that the difference in the life of the TiN coating film was caused by the different rate of the occurrence of the scratching.

The changes by the tempering in the specimen surface and subsurface layer are observed in the following ways. First, it altered the hardness profile in the substrate nitrided layer. That is, the hardness of the near-surface layer was decreased from HV1500 to HV900, approximately, but it was slightly increased at more depth. This seems to have been caused by the desorption of nitrogen from the surface and its diffusion into further depths. The second change was increase in the fracture toughness. When determined by indentation of the surfaces with a conical indenter having 200μm tip radius, the minimum indentation load for the appearance of cracks increased from 294N for DM-2-0 to 588N for DM-2-4. Since the TiN coating layer was identical for all specimens, this increase in the fracture toughness was caused by that of the substrate. Finally, the adherence of the TiN coating film to the substrate was improved. When the critical load for the occurrence of film damage was determined on a CSEM scratch tester, it increased from 67N for DM-2-0 to 78N for DM-2-4. It is reasoned this improved adherence was brought about by the formation of a Ti-rich layer at the interface, which was detected by Auger electron spectroscopy.

Acknowledgement

The experimental work was conducted by Dr. Kawamura at YKK Corp. under guidance of Professor Haruyama at Toyama Prefectural University. The author would like to express his sincere thanks to both of them.