OBSERVATION OF SURFACE AND SUBSURFACE CHANGES DURING SCUFFING IN SLIDING CONTACT

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（滑り接触面のスカッフィング過程における表面と表面層の変化の観察）

区　　分　：甲

論 文 内 容 の 要 旨

Scuffing is a catastrophic and often unpredictable failure of frictional surfaces during sliding or rolling contact. It is often characterized by abrupt increases in temperature, friction, wear rate, noise and vibration, and also by sudden changes in electrical resistance of the contact. Scuffing is a fundamental tribological issue which governs the ultimate performance of machine components such as gear teeth, piston rings and cylinder pairs, cams and follower systems, splines and sleeve bearings. As an important tribological phenomenon, scuffing has attracted extensive research interests during the past several decades. However, the underlying mechanism of scuffing is still insufficiently understood.

This study aims to gain a deeper understanding of scuffing mechanism. To study the process of scuffing experimentally, a concentrated sliding contact was made between a stationary steel ball of SUJ2 steel and a rotational sapphire disc under lubricated or dry conditions. Scuffing of the steel was made to occur at increased normal load and sliding speed. In-situ visual observations were conducted to observe directly the surface changes along the scuffing process. After the sliding tests with in-situ observation, the worn surface, wear particles and subsurface of the contact were further observed using various analytical instruments.

Major findings of this study are as follows: In the initial stage of scuffing, fine wear particles tend to agglomerate at local contact area. The agglomeration causes load concentration and thermal softening of the local steel, which serves as the initial trigger for scuffing. The final stage of scuffing occurs as severe plastic flow of the steel surface, which is initiated at the area of agglomerated particles. The severe plastic flow occurs within a thin layer of a few tens of micrometers beneath the scuffed surface. As scuffing further continues, the severe plastic flow layer turned into a light layer. The changes in crystal structure and hardness along the subsurface indicate that concentrated heating occurs within the severe plastic flow layer and the light layer. Adiabatic shear instability is an important mechanism for the severe plastic flow at the final stage of scuffing.

The thesis is organized into six chapters:

Chapter 1 is the introduction of this study, which includes an introduction of the scuffing phenomenon, a review of the existing models of scuffing, and the objective and contents of this study.

Chapter 2 describes observation and analysis of surface changes in scuffing, including in-situ and ex-situ observation. The instantaneous changes at the contact interfaces were revealed by in-situ visual observation. In-situ contact images were integrated with friction monitoring and wear volume monitoring, thus providing a real-time evaluation of the scuffing process. After the in-situ observation, the worn surfaces were further examined with an optical microscope, SEM, EDX and a surface profilometer. It was found that severe plastic flow, accompanied by rapid increase in friction and drastic expansion of contact area, occurred at the final stage of scuffing. The severe plastic flow areas moved rapidly over the contact area during scuffing. At the area of severe plastic flow, the rate of heat generation seemed to be far larger than the rate of heat dissipation.

Chapter 3 describes observation and analysis on the role of wear particles in the scuffing phenomenon. In-situ observation of frictional areas was conducted to understand the behavior of wear particles in the scuffing process. The shape and composition of the wear particles both prior to and after scuffing initiation were obtained. The profile, composition, and micro-hardness of the steel surface prior to scuffing initiation were also obtained with special interests on properties of the particle agglomerates formed on the steel surface. It was found that scuffing was initiated at the area of agglomerated wear particles. Prior to the scuffing initiation, three types of wear particles were found. The type of wear particles that was characteristic of scuffing was also found. Wear particles influenced the initiation of scuffing via agglomeration, scratch and lubricant starvation. The agglomeration of fine particles, which caused load concentration and thermal softening of the local steel, served as the major effect in the scuffing initiation.

Chapter 4 describes metallographic observation of the subsurface deformation and structural changes of the steel induced by scuffing. Sliding tests were conducted under different sliding speeds and loads, producing different wear states of scuffing, mild wear and steady state dry sliding. Crystallographic changes due to heat and deformation in the subsurface were observed for the three wear states. The change in shear resistance of the subsurface was characterized by variation in micro-hardness along the depth normal to the worn surfaces. The compositional changes induced by scuffing were revealed by EDX and XRD. It was found that the severe plastic flow during scuffing occurred within a thin layer of a few tens of micrometers in the subsurface. The severe plastic flow layer turned into a light layer as scuffing further continued. The crystal grains of the severe plastic flow layer and the light layer became greatly refined or even featureless. Retained austenite could be detected within the light layer after scuffing tests, which indicated the level of temperature rise during scuffing. Below the light layer was a dark zone, which did not experience large plastic deformation but seemed to experience tempering process during scuffing. The severe plastic flow layer and the light layer showed concentrated heating during scuffing. Formation of such a thin layer of concentrated strain and heating was ascribed to adiabatic shear instability.

Chapter 5 suggests a model of the scuffing process, which incorporates major findings of this study. Some suggestions for future work are also presented.

Chapter 6 concludes this study.