Simultaneous Measurement of Frictional Force Fluctuations and Wear Debris Behavior under Semi-Dry Conditions toward Understanding the Creep-Groan Phenomenon

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With the global spread of electric vehicles (EVs), brake noise has become a more serious issue because the quiet operation of EVs makes friction-induced vibration more noticeable than in conventional internal combustion vehicles. In particular, low-frequency noise known as creep groan during low-speed starting has attracted significant attention. Previous studies have suggested that, during drying at the friction interface, wear debris agglomerates on the contact surface, destabilizes the friction force, and promotes friction-induced vibration. However, the agglomeration process of wear debris associated with friction instability, especially its relationship with the material properties of wear debris and brake materials, remains unclear.

In this study, a model friction system consisting of a polydimethylsiloxane (PDMS) plate and an Al2O3 hemisphere was developed using wear debris collected from an actual brake system. By tracking the behavior of water and wear debris at the interface, the mechanism of friction instability during drying was investigated. Special attention was given to how the hydrophilic or hydrophobic nature of PDMS influences friction-force fluctuations caused by water depletion and wear-debris agglomeration. For this purpose, a custom-built rotational sliding friction tester combined with fluorescence microscopy was used.

The apparatus enabled simultaneous mechanical and optical measurements. Friction tests were performed using a PDMS substrate and a hemispherical glass counter surface, while normal load, friction force, and indentation depth were recorded. The interface was observed in both bright-field and fluorescence modes using an aqueous solution containing 0.005 wt.% sodium fluorescein. Hydrophobic and hydrophilic PDMS substrates were prepared, and wear particles collected from an actual brake pad were dispersed near the contact region. Friction tests were conducted under a normal load of 0.5 N at a sliding speed of 1 mm/s for 20 min. To evaluate water retention, fluorescence images were binarized and the fraction of water present was calculated for five regions: inlet, center, outlet, right, and left.

For the hydrophobic substrate, the friction-force signal showed a distinct peak at approximately 100 s after the start of sliding（**see Fig. 1 upper**）. Bright-field images revealed the appearance of particle nuclei near the center of the contact area, followed by agglomerate growth. In contrast, the hydrophilic substrate showed no sharp friction peak; instead, the friction force gradually increased and stabilized at approximately 1 N around 100 s（**see Fig. 1 lower**）. Particle agglomeration started earlier and developed more gradually on the hydrophilic surface. Water-distribution analysis showed that the hydrophobic substrate dried relatively quickly, and the water fraction in the inlet region became zero at almost the same time that the friction force rapidly increased. This indicates that particle agglomeration occurred after local drying and that interruption of water supply caused friction to rise. The subsequent formation of a particle agglomeration layer then stabilized the friction force. On the hydrophilic substrate, water was retained longer and supplied more effectively to the center region, promoting agglomeration-layer formation before complete drying and leading to earlier friction stabilization.

These results indicate that friction instability during drying is caused by water depletion and the accompanying agglomeration of wear debris, whereas rapid and stable formation of a wear-debris agglomeration layer can suppress this instability. The findings further suggest that improving the water-retention capability of the friction material, for example by using a hydrophilic substrate, is effective for stabilizing friction behavior during drying.

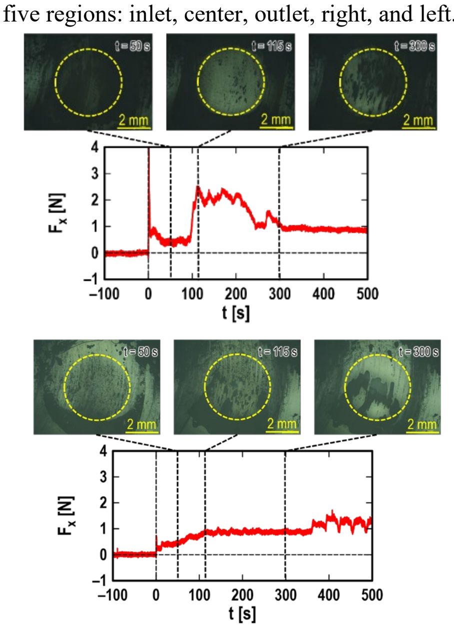

Fig. 1 Time-series of friction force and corresponding snapshots for hydrophobic and hydrophilic substrates

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