

Evaluation Metrics of Hydrogen Embrittlement Resistance under Dynamic Loading Conditions

Susumu Maeda¹⁾ Junya Suzuki²⁾ Tatsuya Houda¹⁾ Hideki Tanaka²⁾

Shuji Ichijo¹⁾ Mizuki Nihira¹⁾ Kazuto Goto¹⁾

1) Honda R&D Co., Ltd.

4630 Shimotakanezawa, Haga-machi, Haga-gun, Tochigi, 321-3393, Japan

2) Honda Motor, Co., Ltd.

52-1 Hagadai, Haga-machi, Haga-gun, Tochigi, 321-3325, Japan

KEY WORDS: Materials, Special steel, Bearing, Hydrogen embrittlement, Test/Evaluation (D3)

This study investigates hydrogen embrittlement in axle-support bearings under dynamic loading conditions, focusing on the complex interaction among vibration, tribo-film behavior, hydrogen generation, and material response. While hydrogen embrittlement mechanisms under static loading have been widely studied, dynamic environments introduce additional factors such as fluctuating loads, stick-slip motion, and repeated formation and breakdown of tribo-films, making the phenomenon more difficult to quantify and evaluate. The authors propose that hydrogen embrittlement in dynamic systems should be understood as a sequential process (Fig. 1): tribo-film breakdown leads to direct metal contact, which triggers hydrogen generation and ingress; hydrogen then accumulates at lattice defects, forming vacancy clusters that evolve into voids. These voids act as stress concentrators and eventually lead to crack initiation and propagation. Importantly, the study emphasizes that white etching areas (WEA), often used as indicators, are not the primary cause of failure but rather secondary features formed after extensive plastic deformation. To experimentally investigate this mechanism, two material-level test methods were utilized: Roller Pitching (RP) tests and 2DISK tests. RP tests simulate rolling-sliding contact under dynamic conditions and enable observation of tribo-film breakdown induced by vibration. 2DISK tests, on the other hand, allow precise control of contact conditions and enable real-time monitoring of tribo-film formation via insulation resistance. Results from both tests consistently show that lubricant-dependent tribo-film formation and retention strongly influence the occurrence of metal contact and subsequent hydrogen ingress.

A key finding is that certain lubricant components, specifically low-molecular-weight higher alcohols (LMHAs), inhibit tribo-film formation by preferential adsorption on nascent metal surfaces. Oils containing such components exhibit lower film-forming capability, leading to increased metal contact frequency, enhanced hydrogen entry, and accelerated void formation. Under vibration conditions, these effects are amplified, highlighting the importance of tribo-film stability in dynamic environments. To translate these findings into practical evaluation criteria, bearing-level tests were conducted under controlled vibration conditions. Based on microstructural observations, void density was introduced as a quantitative indicator of hydrogen embrittlement susceptibility. The void density was defined as the number of voids exceeding a specified size within a defined observation area. Experimental results demonstrate that oils with poorer tribo-film performance result in significantly higher void densities (Fig. 2), correlating well with reduced fatigue life and increased embrittlement risk. The proposed void density metric provides two major advantages: it enables early detection of embrittlement risk without relying on macroscopic failure, and it allows relative comparison of materials and lubricants under realistic operating conditions. This makes it a practical tool for design optimization, lubricant selection, and durability assessment in both internal combustion engine (ICE) and electric vehicle (EV) drivetrains. In summary, the study demonstrates that hydrogen embrittlement in dynamic systems is primarily governed by tribo-film stability rather than traditional microstructural indicators. By introducing void density as a measurable indicator, the authors establish a practical framework for evaluating and mitigating hydrogen embrittlement in real engineering applications.

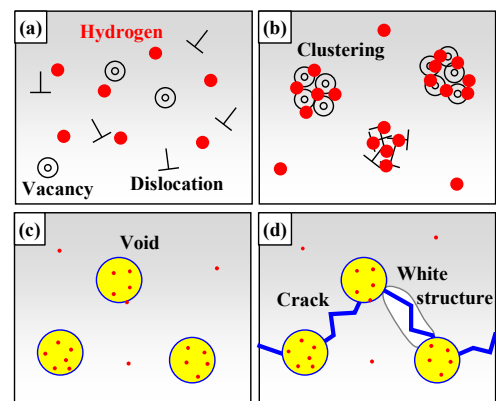


Fig. 1: Schematic illustration of the process leading to hydrogen embrittlement failure: (a) Initial stage (b) Concentration of hydrogen at defects (c) Void formation by divacancies (d) Failure caused by crack propagation between voids.

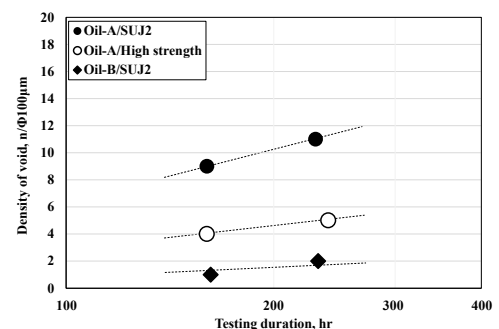


Fig. 2: Void density results after Bearing test