Data Article

Data of dynamic microscale strain distributions of Ti-6Al-4V alloys in dwell fatigue tests

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Dynamic microscale strain distributions with temporal resolution of 1 s in a smooth and a cracked Ti-6Al-4V alloys during one-cycle dwell fatigue tests are illustrated in videos (URL: https://drive.google.com/drive/folders/1pit_VV2apGOpETVfA-JAAt5Xi2CNOiJ3?usp=sharing). The tensile strain distributions were measured by the video sampling moiré method from the 1-μm-pitch grid images in a scanning electron microscope. The strain concentration factors of the smooth and the cracked specimens are 1.96 and 2.65, respectively. The plastic strain increment is 0.0007 during the displacement holding time of 591 s in the smooth specimen at maximum stress of 900 MPa, and 0.0008 during the displacement holding time of 593 s in the cracked specimen at maximum stress of 870 MPa. The typical strain results are analyzed in 1-s-resolved strain mapping in Ti-6Al-4V alloys during dwell fatigue in SEM by video sampling moiré [1].

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2352-3409/ © 2019 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
1. Data

The shared data are 1-μm-pitch grid images and the 1-s-resolved strain results on Ti-6Al-4V alloys during dwell fatigue tests URL: https://drive.google.com/drive/folders/1pit_VV2apGOpETVfajAAAt5Xi2CNOij3?usp=sharing. The analyzed grid images were located at the center of a smooth Ti-6Al-4V alloy, and near a crack tip originated from a notch artificially made at the center of a cracked Ti-6Al-4V alloy (Fig. 1), respectively. The strain distribution in the tensile direction of either specimen was calculated from phase analysis of the spatial phase shifting sampling moiré fringes generated from a single grid image (Fig. 2) at each moment. Video 1 shows the dynamic strain distributions in a smooth Ti-6Al-4V alloy in one-cycle dwell fatigue test with maximum tensile stress of 900 MPa. Video 2 presents the dynamic strain distributions in a cracked Ti-6Al-4V alloy in one-cycle dwell fatigue test with maximum tensile stress of 870 MPa. In Videos 1 and 2, X indicates the tensile direction and the scale is 10 pixels/μm. Image folder 1 depicts the original strain distributions of the cracked Ti-6Al-4V alloy, where the strain concentration occurs above the crack tip at the maximum load and almost disappears after unloading. Table 1 lists the loading parameters, and the summarized strain results in 54 × 38 μm² of the smooth specimen and 54 × 20 μm² above the crack tip of the cracked specimen.

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2. Experimental design, materials and methods

2.1. Materials and grid fabrication

The specimen material was Ti-6Al-4V bimodal titanium alloy [2]. A smooth specimen and a cracked specimen were prepared by mechanical polishing. 1-μm-pitch grids were fabricated on both specimens by electron beam lithography. The electron beam resist (EBR-9, Toray) was spin-coated on either specimen at 2000 rpm for 60s, baked at 195 °C for 30 min [3], and then exposed with electron beam in a scanning electron microscope (SEM, Quanta 200 FEG) combined with a pattern generator (SPG-724,

Fig. 1. Locations of analyzed areas in Ti-6Al-4V alloy specimens and 1-μm-pitch grid images.

Fig. 2. Moiré generation process and phase measurement principle of the sampling moiré method, where \( p \) is the grating pitch and \( T \) means the sampling pitch.
Sanyu Electron). Then, the resist was developed in a Type 1 solution for 60 s and rinsed in a 2-propanol solution for 30 s to generate a grid pattern on either specimen. To ensure SEM observation without the trouble caused by electrostatic discharge, the resist grid pattern was covered by a very thin gold layer using an ion coater (IB-5, EIKO Engineering).

2.2. Dwell fatigue test

The specimen size, the one-cycle 10-min dwell fatigue tests, and the dynamic grid image recording were detailly described in Ref. [1]. The dwell fatigue experiments were performed in anther SEM (JEOL IT300) equipped with an in-situ tensile stage (Gatan Mtest5000). The maximum tensile stress was 900 MPa and 870 MPa for the smooth and cracked specimens, respectively. The scanning speed was 1 image per second at a resolution of 640 × 480 pixels.

2.3. Strain measurement

The strain analysis areas on both specimens were located at the specimen centers as seen in Fig. 1. In the dynamic grid images of either specimen, the grid pitch was around 10 pixels. The dynamic strain distributions in the tensile direction were calculated from the grid images by the developed video sampling moiré method. The recorded video images (10 fps) were sampled over time according to the SEM scanning speed (1 fps), and then the selected images by time sampling were analyzed by spatial sampling moiré.

To reduce the influence of heavy noise on the strain measurement, multi-stage filtering was used in multiple calculation steps and the detailed filter sizes were introduced in Ref. [1]. Each grid image was first used to extract vertical grating perpendicular to the tensile direction by a low pass filter with half the length of 10 pixels. From each extracted grating, the sampling pitch was set as 10 pixels and 10-step sampling moiré fringes were generated. The moiré generation process [4,5] from a grating and the corresponding moiré phase is presented in Fig. 2. Each moiré phase was calculated by a spatial phase shifting technique. Then each strain distribution was calculated from the differential of the phase difference before and after deformation using a local phase unwrapping algorithm [6].

2.4. Video production and numerical analysis

The measured dynamic strain distributions, and the corresponding SEM grid images as well as the loading curves in the smooth and cracked specimens at the time scale of 1 s, were made into two videos at the frame rate of 10 fps in Matlab, as shown in Videos 1 and 2. The typical strain distributions and the analysis were shown in Ref. [1].

### Table 1

| Specimen       | Smooth | Cracked |
|----------------|--------|---------|
| Loading Speed (MPa·s⁻¹) | 18     | 11      |
| Maximum tensile load (MPa) | 900    | 870     |
| Displacement holding time (s) | 591    | 593     |
| Fluctuation of average strain during dwell | 0.0082–0.0096 | 0.0140–0.0154 |
| Fluctuation of maximum strain during dwell | 0.0148–0.0251 | 0.0290–0.0498 |
| Fluctuation of maximum strain with 10s filter during dwell | 0.0173–0.0189 | 0.0334–0.0438 |
| Fluctuation of strain concentration factor | 1.90–2.11 | 2.33–2.94 |
| Mean of strain concentration factor | 1.96   | 2.65    |
| Growth rate of average strain (s⁻¹) | 1.1 × 10⁻⁶ | 1.4 × 10⁻⁶ |
| Growth rate of maximum strain (s⁻¹) | 2.6 × 10⁻⁶ | 1.4 × 10⁻⁵ |
| Average strain increment during dwell | 0.0007 | 0.0008 |
| Unloading speed (MPa·s⁻¹) | 16     | 13      |
| Plastic strain after 1-cycle test | 0.0010 | 0.0014 |
The strain concentration factor in Table 1 were calculated from the maximum strain divided by the average strain, where the maximum strain was smoothed by a time filter of 10s to attenuate the effect of heavy noise on the maximum strain fluctuation. The growth rates of the average and maximum strains in Table 1 were obtained by linear fitting of the average strain and the smoothed maximum strain, respectively.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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