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EXPERIMENTAL DETERMINATION OF RELATIVE SLIPPING DURING FRETTING FATIGUE TESTS

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Abstract: *This paper briefly summarizes basic facts about fretting fatigue phenomena. It discusses the method of fretting fatigue measurement and partial slip estimation. It further it describes the set-up of the experiment in detail, the optimal configuration of the optical system and the technique of postprocessing the acquired image data. The results of the carried out experiment are shown and discussed.*

Keywords: ***Fretting, experiment, relative slips, digital image correlation.***

1. Introduction

At present, most construction failures are caused by fatigue. Fatigue can be seen as a continuous and irreversible degradation of material which occurs at microscopic level. From the macroscopic point of view it has quite a random character. The use of physical models for fatigue damage prediction that involve its nature is difficult and almost impossible in practice. Phenomenological models involving only observed relations among the important factors for fatigue are commonly used.

A fatigue life of a construction can be divided into three basic stages: crack initiation, crack growth and ultimate failure. The first two mentioned stages represent practically the whole fatigue life and can take a very different portion of it depending on the particular case.

The location where fatigue crack initiation takes place can be generally considered as a notch. The stress and strain concentration (the increase of gradient) is a typical characteristic. The contact interface between bodies can also be treated as a notch from this point of view. In the case of pure geometrical notch the stress field in its vicinity is determined only by its shape (beside boundary conditions and material behaviour) contrary to the "contact notch". The fatigue of the contacting bodies is determined not only by their geometry but also by the tribological conditions of the contact interface and by the magnitudes of the relative slips of the contacting surfaces.

1.1. Factors influencing fretting fatigue

The fretting fatigue usually takes place in the vicinity of the contact interface of two bodies with no relative movements. The slips between contact surfaces appear only in the small regions near the border of the contact interface. Flanges, dovetails, hub-shaft connections, cable stands interface, leaf spring washers, leaf and wound springs are typical construction joints that are exposed to fretting conditions.

This type of fatigue is influenced by numerous factors thus it is necessary to be restricted to the most influencing ones. There are three major factors of fretting fatigue. The first and the basic one is the field of strains and stresses in the vicinity of the contact interface. The second one is the amplitude of the partial slips between the contact surfaces. Regarding this factor the contact conditions can be divided into three ranges: the stick range with the slip magnitudes up to 3 μm, the partial slip range with the slip magnitudes between 5 – 50 μm and the gross sliding range with the slip magnitudes greater than 100μm as can be found in Madge et al. (2007) or in Vingsbo et al. (1988). The dependence of the fatigue life on the magnitude of the relative slips is not monotonic but it deeply

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decreases in the range of the partial slips. The third crucial factor is the friction or, generally, tribolological conditions between the contact areas. All the three essential factors influence each other and can change during the construction life.

1.2. Fretting fatigue damage estimations

Both crack initiation and growth stages are usually considered in the models used for fatigue life estimations. The crack initiation may not be the fatigue limit state so the short sometimes long crack growth stage is governing.

The multiaxial fatigue criteria in connection with the critical distance theory described in Araujo et al. (2007) and also in Bhattacharya et al. (1998) are usually used for computations of a number of cycles to crack initiation. It assumes that the physical processes leading to crack initiation take place in small material volume characterised by the length which is considered to be a material property. The summary of these criteria can be found e.g. in Navarro et al. (2008). There are also criteria based on the energy balance concept described in Vidner et al. (2007) requiring a relatively huge experimental base. In connection with the mentioned concepts it is necessary in particular cases to consider also the wear of the material. More about this topic can be found in Madge et al. (2007) and also in McColl et al. (2004).

All computational models, both analytical and commonly used numerical, must be based on relevant experimental data. The parameters of a numerical model are fitted to experimental data with regard to amplitudes of partial slips and the tribological behaviour of the contact surfaces especially.

2. The experiment

In order to develop a reliable numerical model of fretting damage, the first set of experiments was designed and carried out. The goal of these experiments is an estimation of the partial slips between the contact surfaces. The amplitudes of the partial slips can be expected in order of μm and there is a need to probe them along the contact area (in order of mm) with a sufficiently small spatial step. The above requirements can hardly be met using conventional experimental methods, thus optical measuring system using the digital image correlation method was employed.

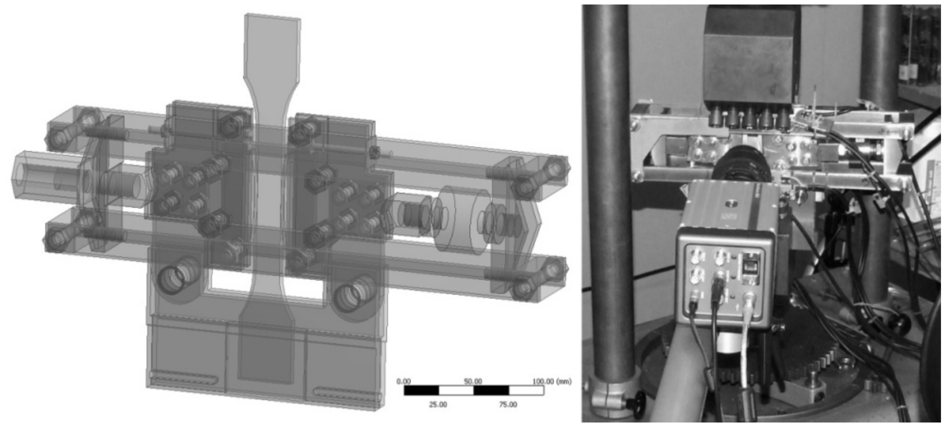

Fig. 1: Design of the fretting fatigue device (left) and experimental set-up (right).

2.1 Set-up of the experiment

The fretting fatigue experiment was carried out on a classical dog-bone specimen (with a cross-section of 15 mm width and 6 mm thickness) mounted in a special device with cylindrical pressure pads with the radius of 200 mm. The design of this device and the whole experimental set-up can be seen in Fig. 1. The whole device with the specimen was fixed in jaws of an electromagnetic Amsler loading machine. The specimen was loaded by static pressure force P (with magnitudes 5, 10 and 15 kN) and by sine cyclic force F (with the mean 10 kN and amplitude 9 kN) with the frequency 100 Hz caused by the Amsler machine. The data were acquired during a relatively short period of about 50 cycles after every 200 thousand cycles. The data related to the sequence of images of the contact interface, traction force transmitted by pads and pressure force P were gathered.

The Dantec Dynamics Q-450 optical system was used for relative displacements measurements. Since displacements in order of μm had been measured at high frame rate, the demands on pattern quality and lighting were quite high. Regarding 1Mpix resolution of CCD chip the objective and extension tubes were used to achieve spatial resolution of approximately 8 μm/pix with the field of view of about 5 x 8 mm. The viewed surfaces were clothed in a very fine contrast stochastic speckle pattern created with airbrush considering the recommendations in Sutton et al. (2009). Two special high frequency lamps with 1 kW power each were used for sufficient lighting. The images of the vicinity of the contact interface between the specimen and pad were recorded by a high speed NanoSense Mk III camera with the frequency of 2 kHz (corresponds to 20 images per loading cycle).

2.2. Evaluation and results

The acquired sets of image sequences were processed in the commercial image correlation software Istra 4-D. The images were divided into two rectangular regions corresponding to the specimen and pad. In each area the displacements were evaluated in a 0.1 mm (12 pix) equally spaced grid. Each grid point corresponds to a subset 0.2 x 0.2 mm (25 x 25 pix). The obtained results were exported into hdf5 file format for further postprocessing in Matlab.

With regard to the noise corruption of the displacement data, the appropriate filtering should be done in order to obtain the relevant data. The uncertainty and confidence margins of displacements were consequently estimated. The results in the regions of interest were gathered and eventually plotted. Parametric scripts using Matlab were created to accomplish the mentioned postprocessing operations.

At first the region where the contact takes place was estimated. The point with maximal contact pressure (and thus the centre of contact area) was estimated on the basis of displacement field in case of pure pressure loading of magnitude 10 kN as shown in Fig. 2. At this point, a coordinate system for relative slip evaluation was introduced. The Hertz contact theory was used for the estimation of the contact area width.

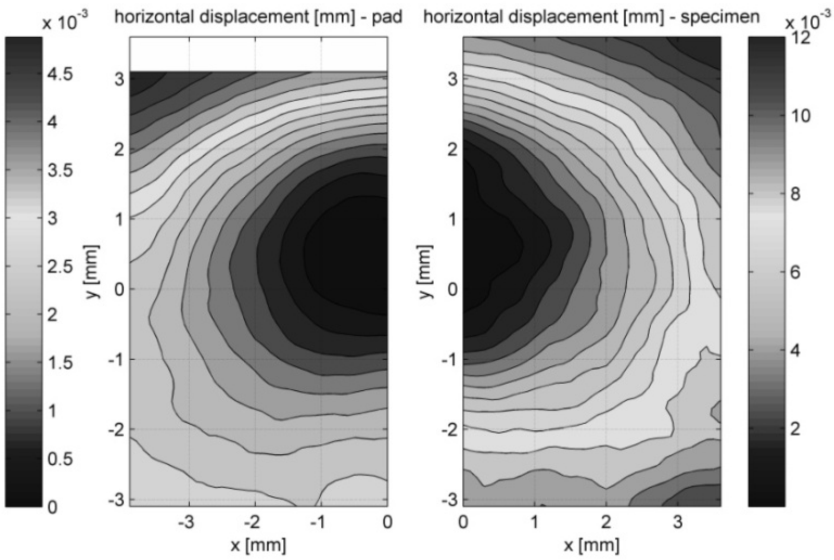

Fig. 2: Horizontal displacement distribution on the surface of the pad (left) and specimen (right) in case of pure pressure loading 10 kN.

The relative slips were computed as a difference between displacements along a line near the contact edge on the pad and specimen. The state corresponding to mean force F was taken as a reference. The relative slips were evaluated for states of maximal and minimal cyclic force F in one period. It corresponds to peaks in tension and compression in relation to the reference state. The displacements were previously smoothed by the disc filter with radius 12, thus they differ from the measured ones. The sum of squares residuals between the measured and smoothed data was used for displacement standard deviation estimation. The standard deviations estimations are taken on a 95 % confidence level. The measured relative slips for the three magnitudes of pressure force (5, 10 and 15kN) are shown in Fig. 3. The confidence margins corresponding to standard deviation are marked. So these margins represent bounds for approximately 68 % of the relative slips.

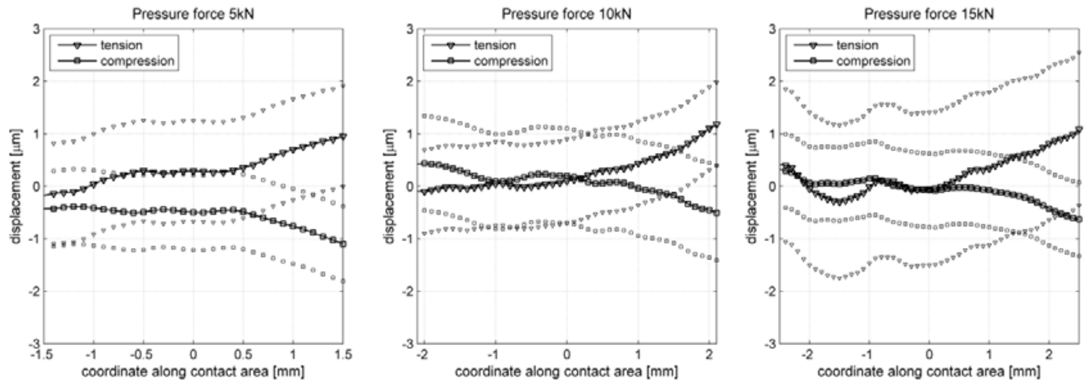

Fig. 3: Relative displacement in contact regions for different pressure forces.

3. Conclusions

Fretting fatigue tests were carried out in order to obtain relevant data for numerical model fitting and verification and in order to estimate amplitudes of relative slip in the contact interface. The displacement field in the contact region (8 x 5 mm) was measured and evaluated by the Q-450 Dantec Dynamics optical system and consequently processed in Matlab. The data related to pressure force and traction force transmitted through the contact interface were acquired. The methods for contact area location, partial slips evaluation and their confidence margins estimation were created and used on the measured data set.

Several conclusions based on the experimental results can be drawn. Firstly it must be mentioned that the confidence margins of the relative slips are quite wide and thus the slip amplitudes should be seen from the statistical point of view. Nevertheless, the tendency of the partial slip to decrease with increasing pressure force is quite obvious, especially between 5 and 10 (15) kN. Secondly there probably was pure slip regime for 5 kN case contrary to the other two. For 10 and 15 kN cases slight asymmetry between the slips in tension and compression can be observed. It could be caused by the fact that the pressure force does not intersect the axis of the cylindrical pad. The amplitudes of partial slips seem to be insufficient and the whole contact could be considered as sticking. This disadvantage of the current configuration could be probably suppressed by an increase of the cylindrical pad radius.

Acknowledgement

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