Design, instrumentation and control of a force/displacement controlled rotating bending fatigue test rig

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Abstract. This paper describes the design, instrumentation and control of a modular four point rotating bending setup for fatigue experiments on both plastic and metal samples of various lengths and diameters. The main goal of this work is to develop a versatile and inexpensive test rig, consisting of commercially available components, and capable of accelerated fatigue testing in either force or displacement control. The resulting test setup has proven to be suitable for this purpose. Metal and plastic samples of various diameters (2-26mm) and lengths (100-300mm) can be tested at repeated loading in bending at test frequencies up to 100Hz. This manuscript reports on the working principle of the test rig, important design choices, sensors and control strategy. Also the in-house developed pneumatic actuator is described, as well as the calibration procedure and first results of fatigue tests on aluminium 7065 T6 samples.

Introduction

The determination of the fatigue life of a mechanical component subjected to cyclic loading is a critical and often time-consuming step in the design cycle of a product [1]. It is generally accepted that conventional analytical tools and traditional safety factors are not sufficient for reliable fatigue life predictions of safety-critical components. Simulations with numerical models offer a solution, but the accuracy of these methods is often limited. Therefore, physical experiments on test specimens and/or full-scale prototypes are necessary to validate analytical and numerical fatigue life estimates of safety-critical components. However, conventional fatigue life experiments require considerable time and resources and are therefore often limited, with larger uncertainty in the fatigue life predictions as a result [2]. In this work, the design, fabrication and first use of a force/displacement controlled fatigue test rig is discussed. This fatigue setup is based on A. Wohler's rotating bending setup [3] and offers novel features. It consists of commercially available components and can operate under controlled force or controlled displacement at test frequencies up to 100Hz. Constant or variable amplitude loads and room-temperature control are possible. Hence, it offers an inexpensive and efficient means for experimental validation of analytical or numerical fatigue life predictions of cylindrical components.

Test rig concept

Fig. 1 indicates the mechanical components of the test rig. The test specimen (D) is connected with the two spindles by means of ER-type clamping chucks. This makes it possible to easily mount specimens of different diameters (2-16mm) using conventional ER-collets. Furthermore, it allows perfect alignment with the two rotating spindles that are mounted by means of ball-bearings in the cylindrical housings (B) and (E). A specially developed pancake synchronous motor of 1kW is used to drive the left spindle in its housing (B). By doing so, both spindles and the test specimen can rotate at a rotational speed ranging from 60 to 6000rpm.

As shown in Fig. 1, the cylindrical housings (B, E) are both mounted with ball-bearings in fixtures (C, F). The left fixture (C) is stationary, while the right fixture (F) is mounted on a high precision linear slider (I). This slider enables fatigue tests of samples of different lengths (10-300mm) as well as (dis)mounting specimens.

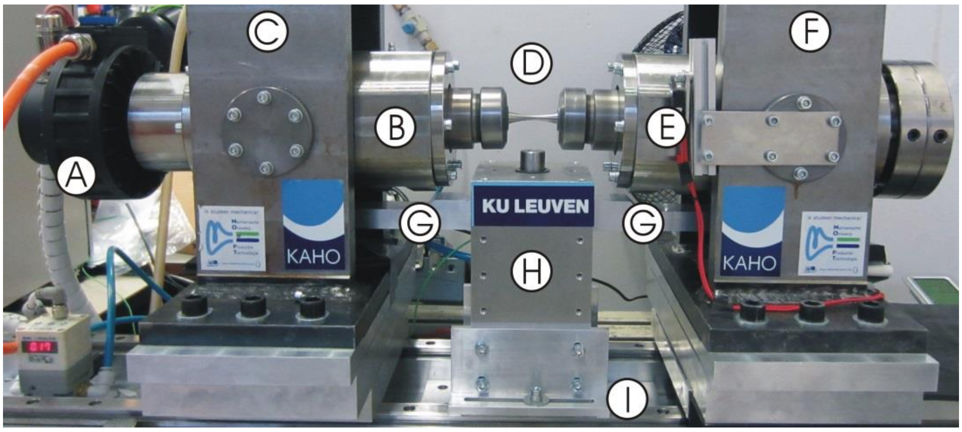

Fig. 1. Test rig concept and components

Fig. 2 indicates the loading mechanism. By means of an in-house developed pneumatic actuator (H) the actuation beam (G) can be lifted upwards with a constant force F. This force then splits into two forces $F/2$, acting on the left and right spindle respectively. Since both spincles can rotate in their fixtures by means of bearings, the forces $F/2$ and the lever arm L result in a constant bending moment $M = FL/2$ over the total length of the test specimen. Fatigue tests can be performed in force or displacement control by means of a NI CompactRio controller and multiple sensors. Force is measured during tests using a capacitive force cell on top of the pneumatic actuator. This force cell is calibrated by means of a clamped test sample with strain gauges. The curvature of the specimen is determined by means of a laser vibrometer that measures the vertical deflection of the driven housing (E). Using the CompactRio controller, tests can be performed under controlled load or under controlled displacement. In addition, the surface temperature of the rotating specimen is measured with an IR sensor. This enables room temperature controlled testing by adaption of the rotational speed based on the measured sample temperature. The in-house developed pneumatic actuator has a dynamic stroke of 100mm and a force range of 100N to 2500N. Thanks to the closed loop control, sinusoidal loading in bending can be applied under constant or variable load amplitude. To increase the bending moment range, three lever arm lengths (*L* = 35, 70, 105mm) can be used as illustrated in Fig. 2. This bending moment range is sufficient to test specimens of different diameters and different materials. The bending stress σ_b can be calculated as function of force *F*, length *L*, diameter *d*, test frequency *f,* and time *t* as shown in Eq. 1.

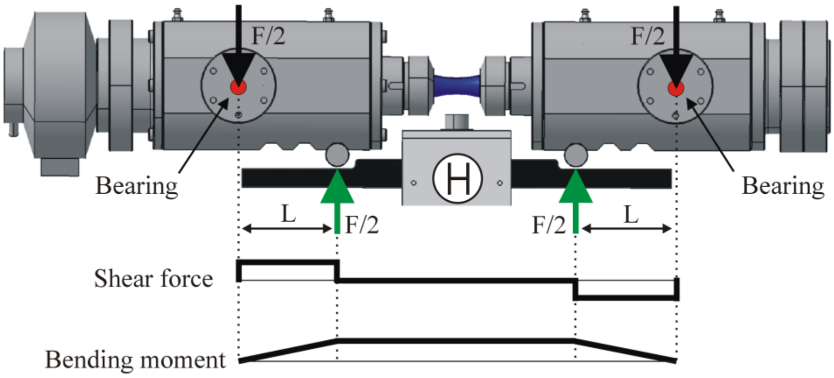

Fig. 2. Loading principle of the test rig

$$\sigma_b(t) = \sigma_b\, sin(2\pi f t) = \frac{M\left(\frac{d}{2}\right)}{I}\sin(2\pi f t) = \left(\frac{16}{\pi}\right)\frac{F\cdot L}{d^3}\sin(2\pi f t) \qquad (1)$$

First results

First experiments were performed on aluminium 7075 T6 samples for which SN-data of rotating bending fatigue tests is widely available in literature [4]. Specimens were machined according to DIN 50113 [5] and tested at three different constant stress amplitudes at room temperature. The resulting fatigue data corresponds well with literature data, as shown in Fig. 3. Currently, further tests are ongoing on Ti6Al4V, PA12 and ABS samples.

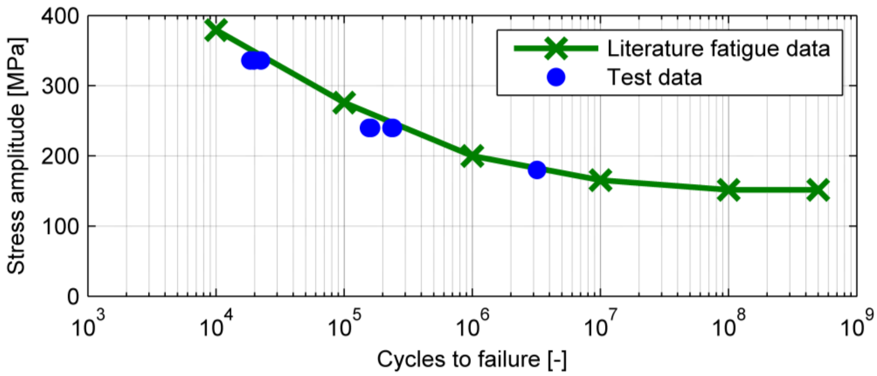

Fig. 3. Fatigue data of Aluminium 7075 T6 samples

Conclusion

A versatile and inexpensive concept for accelerated fatigue tests in rotating bending has been presented. The in-house developed pneumatic actuator allows for constant- and variable amplitude bending loads. Test frequencies up to 100Hz can be achieved and test can be performed under controlled force or controlled displacement.

References

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