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A critical insight on the use of external load cells for fatigue tests in pressurized systems

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ABSTRACT

For fatigue studies, load cells are generally used to measure the cyclic loading applied to the specimen. However, the literature reports that an internal force arises when fatigue tests are performed inside pressurized vessels, acting directly on the vessel shaft. Another component, the friction force, arises due to the sealing system. These two forces impose substantial differences between the values measured by external load cells and the true loading applied on the specimen. Faced with this problem, this study aims to analyze the influence of friction in pressurized testing of corrosion-fatigue, the sealing system of which has been specially designed with reduced stick-slip effect to avoid nonlinearities in the cyclic load. A new methodology based on a strain gauges system installed on the CT specimen was developed and tested, solving the problems of cyclic load and crack length measurements for corrosion-fatigue tests under high pressure. The innovation of this system is that the specimen itself simultaneously acts as a crack length transducer and a load cell. Such a system was properly designed to be used under high pressures and is resistant in aggressive environments. Therefore, it is possible to perform corrosion fatigue tests, obtaining Fatigue Crack Growth Rates (FCGR) without all the measurement problems caused when a load cell is used. In addition, the resulting errors obtained when using a classical load cell in the tests can also be measured by the present experimental setup. In this paper errors were verified in corrosion-fatigue tests using a conventional load cell. These errors could be greater than 700 percent, not meeting the requirements of ASTM E4 and E647 standards. Consequently, the crack length measurements do not agree with the values obtained by an optical microscope, even when tunneling does not occur.

1. Introduction

In 1979, Deans designed a system using a single strain gauge to monitor crack lengths called BFS, Back Face Strain [1]. Recently, Newman improved the accuracy and increased the range of crack length measurement using BFS, showing a suitable methodology for low-pressure fatigue tests [2–6]. This improvement was included in the ASTM E647 [7]. However, its application is not suitable for tests under high pressure, since it depends on an external load cell for load measurements. Indeed, problems with measuring loads applied to test specimens located inside pressurized vessels using conventional load cells have been reported since 1979 [1] and recently emphasized [8]. Consequently, for pressured systems the whole

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propagation curve, da/dN vs. ΔK, will not be accurate if an external load cell is used. In order to reduce inaccuracy caused by this measurement error, it is commonly proposed in practical works a mathematical compensation, or a safety factor. However, the use of these factors could be excessively conservative or even unsafe, because a sealing system can cause at the same time systematic and random errors.

Recently, the LNDC (Non-destructive Testing, Corrosion and Welding Laboratory) developed an integrated system of crack length and load measurements simultaneously, which proved to be adequate to meet the requirements of the standard [7–9]. This strain-gauge system transforms the test specimen itself into a load cell and a crack length transducer. As a result, the use of an external load cell can be disposed of in this system, named here as EFS, Extreme Face Strain Gauges [1,8–10]. In this paper, experimental comparisons between the loading measured by the new system, better detailed in [8], and the external load cell were performed [9]. For this, two different kinds of tests were executed: one with and one without a pressurized vessel. The results showed that in the second case there is a good agreement between the measures; however, in the first case the difference between the results can reach values much higher than the requirements of the ASTM E647, which is two percent. This difference is associated with the error caused mainly by friction force, which increases with the higher pressures and it becomes more important when the load applied under the specimen is decreasing in cycle [11–13]. The results obtained in this work showed that the load error can be higher than 700% in a fatigue test under high pressure.

2. Experimental

This work used the compact tension (CT) specimen, with a 60 mm width (W) and 10 mm thickness (B). Three strain gauges were assembled on it: one uniaxial type placed on the back of the sample, traditionally used for crack length measurement and called BFS, and the two others were biaxial type (XY), forming the so-called EFS system. Both of them were 3 mm length and had resistance of 350 Ω. The two biaxial strain gauges are useful to eliminate discrepancies in load measurement, such as those caused by a slight misalignment, see Fig. 1.

After the strain gauge system was installed in the specimen, it was coated maintaining free the region near the fatigue crack. It is worth noting that it is possible to use various types of coatings to protect strain gauges. However, it is important to consider the following aspects: high corrosion resistance; chemical inertia; relatively lower young's modulus; and good resistance to high pressures. In the present work, a polymeric coating with these properties was used. Shore A - DIN 53505 and Tensile strength at 190 bar, 130 lb per linear inch [6] was chosen [8]. If this coating were very rigid, it would cause problems in the strain gauges measurements, since it would prevent the strain gauge from deforming correctly.

Load versus deformation calibration curves was obtained under two different conditions: without and with the coating. In both conditions, the crack length measured by the strain gauges showed a very good agreement compared with the real value, obtained by optical microscopy, which means that there was no significant restriction of the deformation. In addition, if the coating did not protect the strain gauges well, there would be an incorrect measurement of the crack size during the test, since corrosion would modify the electrical resistance. After the specimen preparation with strain gauges and coating, a pre-cracking was made and then the test started with or without the vessel developed by LNDC. The temperature was always room temperature (23 ± 2 °C). However, the strain gauges used in the present work allow temperatures up to 120 °C.

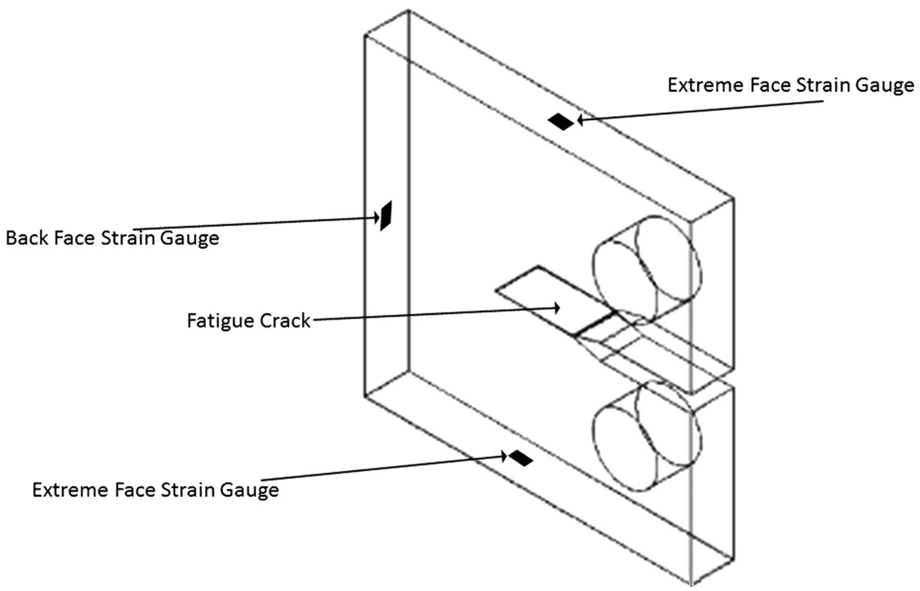

Fig. 1. Positioning of the strain gauges on a C(T) specimen.