Very-High Cycle Fatigue: Size Effects and Applications in Civil Engineering

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Summary

Fatigue life assessment can be carried out according to two well-known approaches. The first is the fatigue damage tolerance (FDT) approach, which is based on Paris' law. The second is the cumulative fatigue damage (CFD) approach, which is based on Wöhler's curve. Both approaches exhibit scale effects.

In the context of the FDT approach, one of the more active areas of research in the field of fatigue has been the understanding of the fatigue crack growth behaviour of the short cracks, which are characterised by higher crack growth rates than expected by decreasing the crack length. Kitagawa and Takahashi noticed that the fatigue threshold increases with the crack length. These anomalous behaviours will be interpreted in the framework of fractal geometry, in which the assumption of the invasive fractal roughness of crack profile will allow finding crack-size dependent scaling laws for the Paris' curve parameters.

Since the introduction of Wöhler's curve, fatigue-testing results on smooth specimens have highlighted that the fatigue life of a structural component depends not only on the stress range. A decrease in the fatigue strength with the specimen size was noticed both in the finite-life fatigue regime and ultra-long fatigue (VHCF) regime. A similar trend was also observed for the fatigue limit. This evidence was revealed also thanks to the application of UFTMs, which made it possible to reduce the testing time. It will be shown that, if the ligament is considered as a lacunar fractal set, negative scaling laws will be found for the coordinates of the limit-points of Wöhler's curve, so that a theoretical explanation will be provided to the decrement in fatigue resistance by increasing the specimen size. Analogously, the hypothesis of the lacunar fractal ligament will allow obtaining similar structural-size dependence of the fatigue limit.

On the other hand, although the application of ultrasonic fatigue testing machines has made it possible to perform tests up to 10^{10} cycles in a very short time, the *quid pro quo* to be paid was that it was more difficult to perform fatigue experiments on specimen sizes larger than 10 mm. In other words, it has never been possible to observe and analyse the decrease in the fatigue life and the fatigue limit with the specimen size over a wide scaling range. In the Thesis, it will be shown the results of a new experimental campaign performed at Politecnico di Torino on a set of hourglass and dog-bone specimens made of EN AW-6082 aluminium alloy, spanning over a wide dimensional range. The fatigue tests were carried out with the ultrasonic fatigue testing machine developed by the Italian company Italsigma up to 10^{10} cycles. The nominal diameters of the cross-section of each sample set were 3, 6, 12, 24, and 30 mm, respectively. As expected, Wöhler's curve moves downwards, and the conventional fatigue limit assessed at 10^{10} cycles decreases, with the specimen size. A good agreement was obtained fitting the fatigue limit data with the Fractal and the Multi-Fractal Scaling Laws. On the other hand, a comparison between the two different scaling laws demonstrated that the MFSL is able to fit the experimental data better than the fractal scaling law when a wide dimensional range is considered.

In the last chapter, it will be shown that the phenomenon of very-high cycle low-amplitude fatigue, combined with corrosion degradation, should be considered in the assessment of the remaining fatigue life of existing bridge infrastructures built during the last Century. If the very-high cycle fatigue is approached, even rather limited loading cycles can accumulate a substantial amount of damage. A possible scenario will be proposed to put into evidence how the combined effect of fatigue at very-high number of cycles and corrosion could have been responsible for the failure of one of the strands and the subsequent collapse of the so-called balanced system of the Polcevera Bridge designed by Morandi.