Evaluation of Strain Rate Sensitivity in UFT Testing of Structural Steels

L. Milne[1a], Y. Gorash[1], T. Comlekci[1] and D. MacKenzie[1]

[1] University of Strathclyde, Dept. of Mechanical and Aerospace Engineering, 75 Montrose Street, Glasgow, G1 1XJ, UK

[a] lewis.milne.2015@uni.strath.ac.uk

Abstract

Traditionally in the fatigue design of steels, a fatigue limit is considered at around 10^6 cycles, beyond which it is assumed the plastic strain generated within the material is negligible and the fatigue life is therefore infinite. In recent years, however, it has become apparent that this infinite life assumption is not accurate [1]. Thus, to ensure the extended service lives of industrial components, the fatigue behaviour beyond the traditional fatigue limit and into the so-called "very high cycle fatigue" (VHCF) regime must be evaluated. The VHCF regime is typically defined as the 10^6 – 10^{10} cycle region, however testing to this number of cycles using traditional fatigue testing methods is prohibitively time consuming and expensive.

As such, a faster method of fatigue testing has recently been developed, known as Ultrasonic Fatigue Testing (UFT). Through the use of piezoelectric actuation and specimens tuned to vibrate at their resonant frequencies, UFT machines can achieve cyclic loading at 20 kHz. As such, fatigue results can be produced in a fraction of the time of traditional methods, reaching 10^{10} cycles in just 6 days.

UFT, however, has several drawbacks which are yet to be fully understood. Chiefly among these is the strain rate effect. The increased strain rate inherent in the 20 kHz loading will significantly influence the material properties, leading to variations in the fatigue behaviour of the materials which are yet to be fully explored [2,3]. This strain rate effect varies between materials, but is particularly notable in body-centred cubic metals such as ferritic structural steels [2,3]. As such, S-N curves produced through UFT for structural steels are difficult to compare to traditional S-N curves and are as of yet unusable for design purposes, as can be seen in figure 1. Therefore, until a method can be developed which takes the strain rate effect into account and allows comparison of fatigue data at a range of different frequencies, UFT has limited usability for this ubiquitous class of materials.

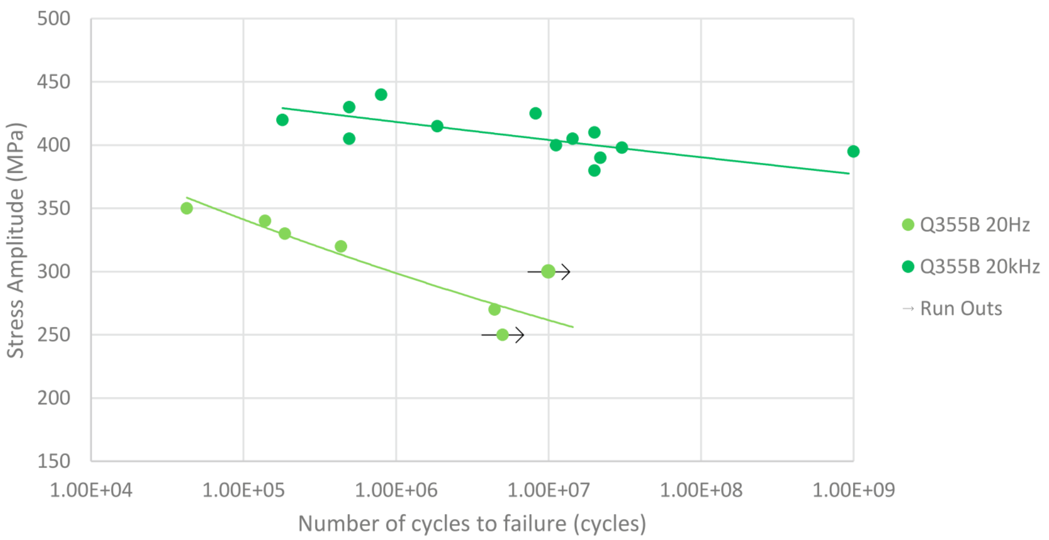

Figure 1 - Effect of Test Frequency on previously tested Q355B steel [4]

The aim of this investigation is therefore to investigate the influence of strain rate on the material properties of several different structural steels and thus quantify the corresponding effect on their UFT behaviour.

To comprehensively evaluate the change in fatigue behaviour at ultrasonic test frequencies, specimens of four different structural steel grades were tested under fully reversed loading at frequencies of 20 Hz and 20 kHz, using Instron 8801 and Shimadzu USF-2000A testing rigs respectively, as shown in figure 2 (a) and (b) below. The same test specimen geometry was used at both test frequencies, and an air cooling system was implemented to keep the UFT test below 30 °C. This reduces the potential points of difference between the two cases to just the test frequency.

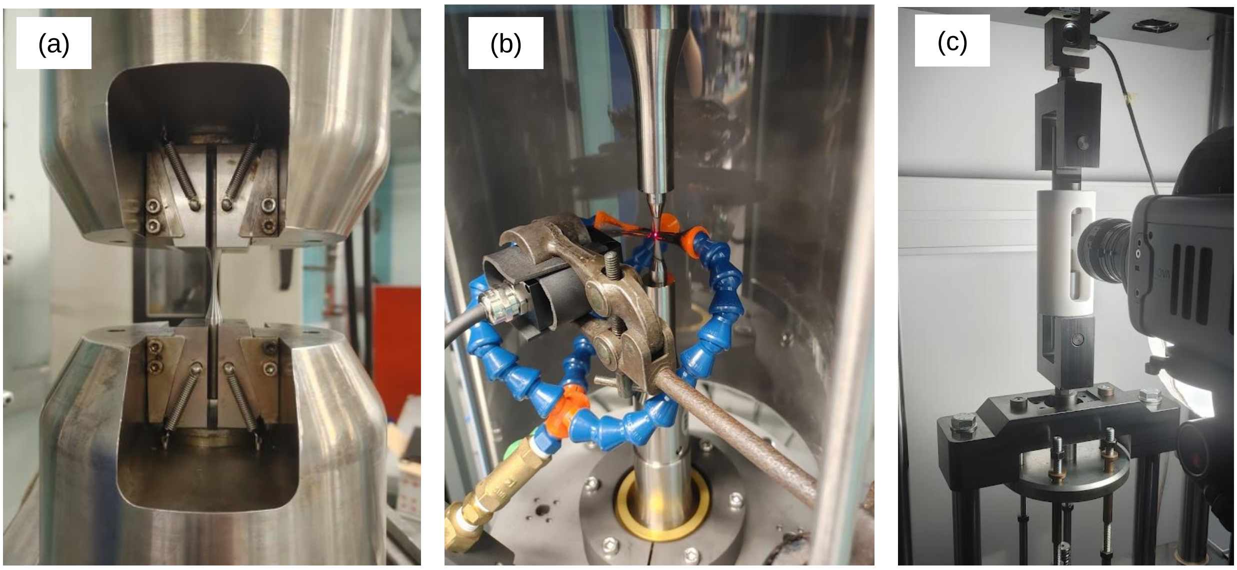

Figure 2: Fatigue Samples in the (a) Instron 8801 and (b) Shimadzu USF-2000A and (c) high strain rate tensile test machines

Based on the fatigue results at the two frequencies, several frequency sensitivity parameters are proposed, which are based on both the finite fatigue life regime and the fatigue limit. These proposed parameters are also applied to UFT data for a number of steels from literature, in order to identify which material properties have the largest influence on frequency sensitivity.

Finally, for the tested steels, high strain rate tensile tests were carried out at strain rates of up to 300 s^{-1} in order to evaluate the increase in yield strength and tensile strength with strain rate, as shown in figure 2 (c). The results will be applied to the modified Arrhenius model proposed by Guennec et al. [5], in order to relate the fatigue strength at the two test frequencies.

References

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