Low-cycle fatigue testing on strain-aged steel reinforcing bars

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Extended Abstract

1.1 INTRODUCTION

During earthquakes, steel reinforcing bars in reinforced concrete structures may be subjected to large inelastic deformation in tension and compression as high as 6% strain, eventually leading to low-cycle fatigue failure (Mander, Panthaki, & Kasalanati, 1994). This was observed in laboratory testing and post-earthquake damage inspections including during the Mw 7.8 Kaikoura earthquake in New Zealand (NZ) (see Figure 1 and Figure 2) (El-Bahy, Kunnath, Stone, & Taylor, 1999b; El-Bahy, Kunnath, Stone, & Taylor, 1999a; Palermo et al., 2017). Earthquakes are usually preceded and/or followed by other events of larger or smaller intensity; longitudinal steel failures may not occur during a first event, but in a subsequent one due to the cumulative damage. Seismic events can also occur several months apart and during this period, if the steel has experienced any post-yielding deformation during the first event, strain ageing takes place, modifying the mechanical properties of the material. In this document, fatigue lives for unaged and aged 12-mm diameter NZ-manufactured Grade 300E reinforcing bars are compared.

Figure 1 Fractured longitudinal reinforcing bars in a bridge pier close to the Mw 7.8 Kaikoura earthquake epicentre.

Figure 2 Detail of fractured longitudinal steel rebar.

1.2 EXPERIMENTAL TESTING

A benchmark strain-life curve for steel Grade 300E reinforcing bars of 12-mm diameter was derived. Steel specimens were subjected to completely reversed cyclic loading ($R = -1$) between constant-strain limits. Tests were conducted in strain control. Fatigue-life curves were obtained by applying a number of strain amplitude cyclic histories, maintaining the mean strain equal to zero. Strain ageing effects on fatigue life were determined by employing the following procedure:

- Specimens were first precycled up to a pre-identified number of cycles: 33% and 66% of the benchmark fatigue life.
- The precycled specimens were aged for four hours at 100°C in boiling water. This is equivalent to 1-year ageing at 15°C (Hundy, 1954; Loporcaro, Pampanin, & Kral, 2019);
- Specimens were cyclically tested (at the same strain amplitudes as in the precycle phase) until failure.

1.3 RESULTS

Experimental fatigue-life results are fitted using the Coffin-Mason model and plotted in Figure 3 and Figure 4. Figure 3 shows that the strain-life curves for the aged (33% pre-cycle) and the benchmark samples are approximately parallel but shifted because the fatigue life of aged samples has been reduced. In **Error! Reference source not found.**, the strain and also superimposed on the unaged strain-fatigue life curve. In this case, the two curves are not parallel: at shorter fatigue lives the curves almost coincide, while at longer fatigue lives, the effect of strain ageing becomes more significant. This is explained because at very short lives, e.g., less than 10, the number of precycles (66% of the original fatigue life) is close to the fatigue life.

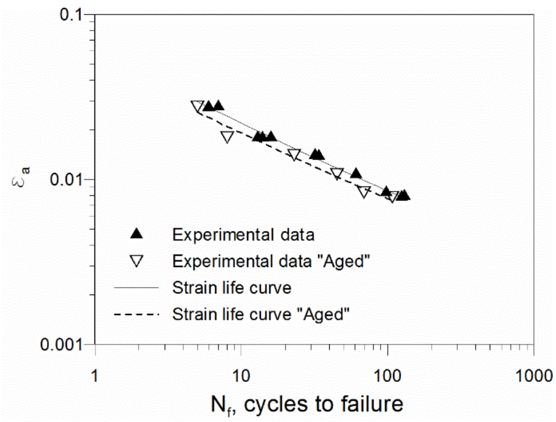

Figure 3 Comparison between unaged and aged samples (33% pre-cycled). Coffin–Manson model using total strain.

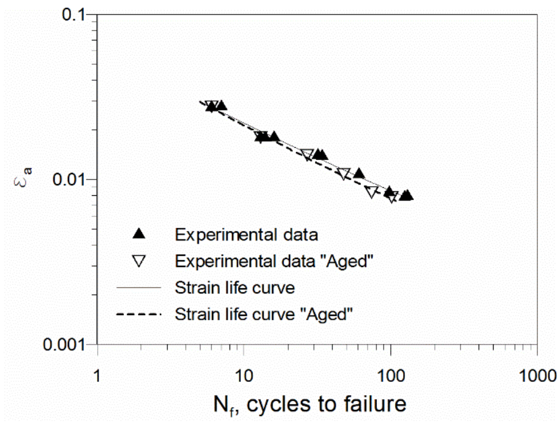

Figure 4 Comparison between unaged and aged samples (66% pre-cycled). Coffin–Manson model using total strain.

A further observation can be made by comparing the expected remaining life (calculated as the difference between the original fatigue life and the precycles applied) with the actual remaining life. A drastic reduction in fatigue life was observed. The remaining fatigue-life loss varied from 20% to 70% in the case of those samples precycled up to 33% of the original fatigue life. In the case of samples precycled up to 66%, the reduction in the remaining fatigue life was more dramatic. It ranged from 33% to 73%, with an average loss of about 53%. Therefore, given the same amount of ageing time, the larger the amount of pre-cycling, the more significant is the remaining fatigue-life loss.

1.4 CONCLUSIONS

The results obtained from the experimental work show that, when the assessment of the remaining fatigue life of steel reinforcing bar is undertaken, strain ageing must be considered. Strain ageing not only affects the monotonic mechanical properties of Grade 300E steel (Loporcaro et al., 2019) but also the low-cycle fatigue life. The remaining fatigue life could be underestimated.

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