The effect of overloading on a ductile adhesive's mode I fatigue behaviour

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Introduction

Most bonded structures experience variable amplitude fatigue (VAF) loading conditions, where overloading is included. Contrary to other materials, where crack growth retardation has been observed, for adhesives, only acceleration effects following overloads have been reported [1-3]. In these studies, brittle adhesives were considered, and thus plasticity induced phenomena, that are associated with retardation, are negligible.

Given the uncertainty associated with the influence of overloads, mainly in ductile adhesives, and the lack of studies on VAF of adhesives, it is essential, to evaluate experimentally the influence of overloads so that these can be included in fatigue life estimation procedures.

Experimental methodology

To achieve this, a double-cantilever beam (DCB) specimen, bonded by a ductile methacrylate adhesive, were used in this study.

Three different loading spectra, as schematically represented in Figure 2 were considered: Constant Amplitude (CA), Single Overload (SO) and Periodic Overload (PO). For the CA fatigue cycles, a frequency of 1 Hz and a load ratio (R) of 0.1 were considered. For the SO spectra, distinct number of cycles to overload (N_{SOL}) and overload magnitude (F_{OL}) were contemplated. Regarding the PO spectra, two number of cycles between overloads (N_{POL}) were used.

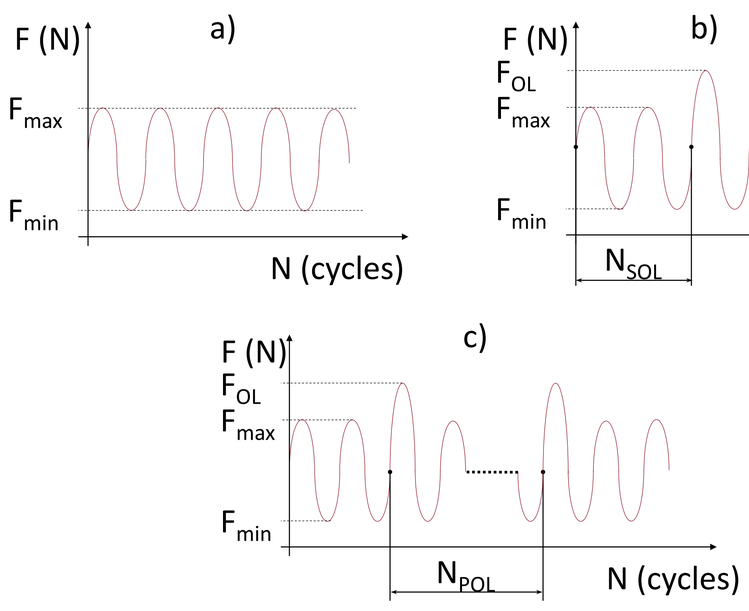

Figure 2 – Considered loading spectra: a) CA; b) SO; C) PO.

Experimental results

Total fatigue life

The fatigue life for all tested conditions is shown in Figure 3. It is shown in Figure 3a that, SOs can increase the fatigue life when compared to the CA condition. Up to an N_{sol}=5500, this increase is greater for higher N_{sol}. Such behaviour is associated to the formation of a higher plastic region ahead of the crack tip, that resists against crack propagation. However, if applied later, the overload causes premature failure as the strength of the joint is reduced due to fatigue damage.

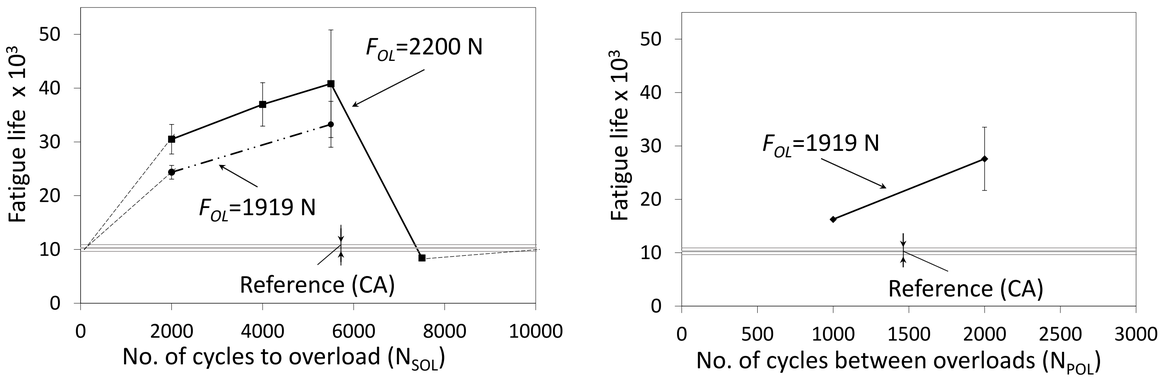

Figure 3 – Total fatigue life results: a) CA vs SO; b) CA vs PO.

Regarding the PO condition, Figure 3b, the increase in the total fatigue life is less significant than for SO, being almost negligible for the lowest N_{POL}. This shows that, very frequent overloads can have a negative impact, mostly due to the nefarious effect that overloads have in later stages of the fatigue life.

Fatigue Crack Growth (FCG) curves

FCG curves were obtained for all conditions using the compliance-based beam method, Figure 4. These, relate the FCG rate (da/dN) with the ratio between the maximum energy release rate and the mode I fracture energy (G_{max}/G_{IC}) .

Regarding the SO condition, after the application of an overload, a sudden increase in fatigue crack growth rate is observed. However, after a certain number of cycles, the da/dN decreases and reaches a minimum value (lower than under CA). Furthermore, the number of cycles spent in this low da/dN region is higher. This is due to the plastic region ahead of the crack tip, that induces residual compressive stresses and resist against crack propagation. Eventually, the crack grows out of this region, and then, the FCG curve assumes a similar shape to the one for CA.

For the PO condition, it can be shown that every overload causes an increase in G_{max}, being more pronounced for later stages of the fatigue life, which is associated with the increase in displacement caused by sudden crack propagation due to repeated overloads. Moreover, the lowest values of da/dN are higher than for SO, showing that the maximum retardation of the overload is not achieved if applied repeatedly.

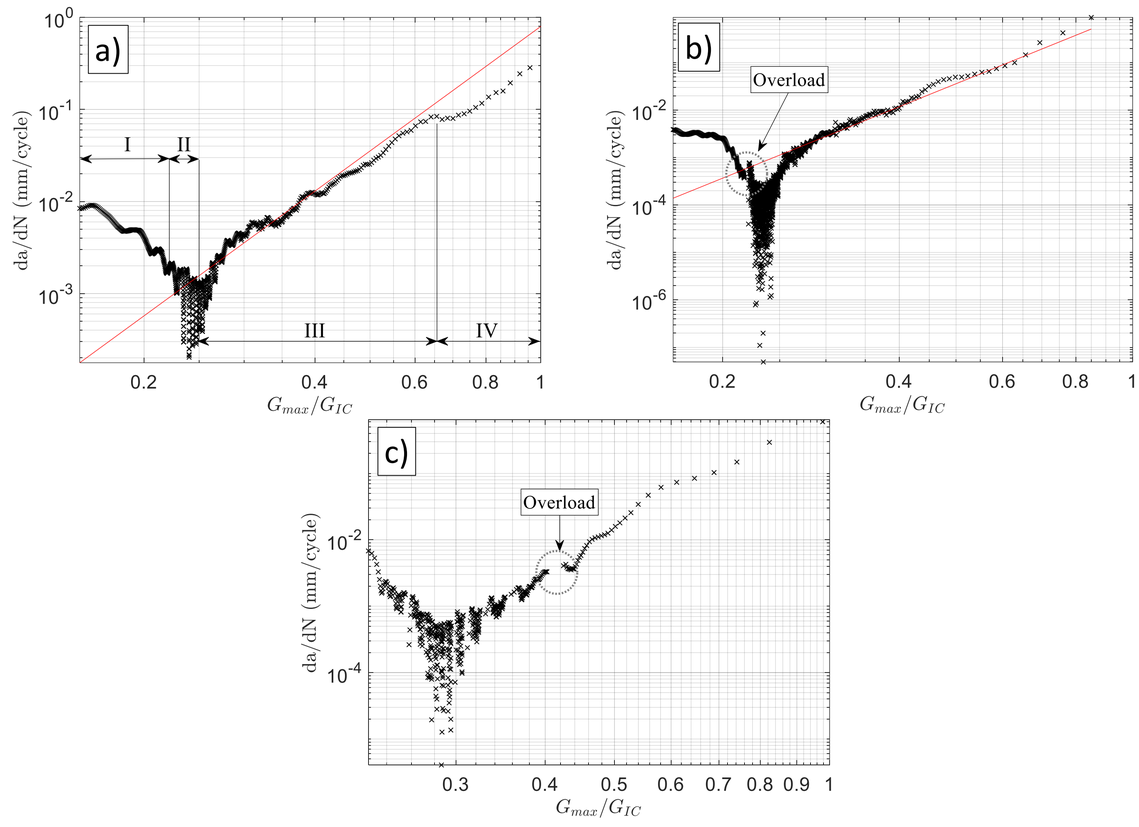

Figure4 – FCG curves: a) CA vs SO; b) CA vs PO.

Conclusions

The presence of an overload can significantly increase the total fatigue life of the bonded joints. This increase can go up to four times when compared to CA, which is associated with the development of plasticity induced phenomena following an overload. However, if applied at later stages, it can have a nefarious effect and quicken the failure.

For the PO spectra, a moderate increase in the total fatigue life is observed for two main reasons: the periodic repetition does not allow the maximum retardation to be achieved and the damaging effect of overloads applied after a certain number of cycles.

References

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