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ScienceDirect

Procedia Structural Integrity 5 (2017) 85–92

Structural Integrity Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal

Plasticity induced closure under variable amplitude loading in AlMgSi aluminum alloys

L.F.P. Borrego[a,b]*, J.D. Costa[a], JA.M. Ferreira[a]

[a] *CEMMPRE, University of Coimbra, Department of Mechanical Engineering, Rua Luís Reis Santos, 3030-788, Coimbra, Portugal*
[b] *Instituto Politécnico de Coimbra, ISEC, Department of Mechanical Engineering,Rua Pedro Nunes, 3030-199 Coimbra, Portugal*

Abstract

Fatigue crack propagation tests under peak overloads, as well as High-Low and Low-High block loading sequences have been performed in aluminum alloy specimens. The observed transient crack closure level is discussed in terms of loading sequence, load change magnitude and ΔK baseline levels. The crack closure level is compared with the crack growth transients. A good agreement between experimental and predicted crack growth rates is obtained when the partial crack closure effect is properly taken into account. Therefore, plasticity-induced crack closure plays an important role on the load interaction effects observed in aluminum alloys.

Peer-review under responsibility of the Scientific Committee of ICSI 2017

Keywords: Damage Tolerance Overloads, block loading, partial crack closure, plasticity-induced crack closure

1. Introduction

Service conditions generally involve random or variable amplitude, rather than constant amplitude loads. Significant accelerations and/or retardations in crack growth rate can occur as a result of these load variations. Thus, an accurate prediction of fatigue life requires an adequate evaluation of these load interaction effects. To attain this objective several type of simple variable amplitude load sequences must be analyzed. Several mechanisms have been proposed to explain the crack growth transients following variable amplitude loading sequences, which includes

* Corresponding author. Tel.: +351 962560101; fax: +351 239790331.
E-mail address: borrego@isec.pt

2452-3216
Peer-review under responsibility of the Scientific Committee of ICSI 2017
10.1016/j.prostr.2017.07.072

models based on residual stress; crack closure; crack tip blunting; strain hardening, crack branching and reversed yielding. However, the precise micromechanisms responsible for these phenomena are not fully understood.

Crack closure has played a central role in the study of fatigue crack propagation, Elber (1970). Generally, under constant amplitude loading, closure measurements produce good correlation between low stress ratio and high stress ratio crack growth rate data, e.g. Blom and Holm (1985), Elber (1971), Borrego et al (2001), through the effective range of K corresponding to a fully open crack, ΔK_{eff}, introduced by Elber (1971).

In spite of some controversy, the effect of residual plastic deformation, which leads to compressive stresses before the crack-tip and raises the crack opening load on subsequent crack growth (crack closure), has been identified as the most important aspect in explaining also the characteristic features of crack growth retardation. However, under constant amplitude loading at the near-threshold regime the measured opening loads are sometimes excessively high because the role of the lower portion of the loading cycle below Kop to the fatigue crack growth behavior is not taken into account, e.g. Hertzberg et al (1988) and Chen et al (1996), resulting in a significant underestimation of the effective crack driving force. Additionally, under single peak overloads some discrepancies appear when the experimental post-overload transients are compared with crack growth rates inferred from remote closure measurements and the da/dN versus ΔK_{eff} relation for the material, Dexter et al (1989), Fleck (1988), Shercliff and Fleck (1990), Shin and Hsu (1993). Among other observations, these behaviors have contributed for some of the controversy around the phenomenon of crack closure.

The present work intends to analyses the crack closure levels on aluminum alloy specimens subjected to several variable amplitude loading sequences and evaluate if the observed transient crack growth behavior can be correlated with the crack closure phenomenon.

2. Material and experimental details

The material used in this research was an AlMgSi1 (6082) aluminum alloy with T6 heat treatment. The T6 heat treatment corresponds to a conversion of heat-treatable material to the age-hardened condition by solution treatment, quenching and artificial age-hardening. The alloy chemical composition and mechanical properties are shown in Table 1 and Table 2, respectively.

Table 1. Chemical composition of 6082-T6 aluminum alloy in wt.%.

Si	Mg	Mn	Fe	Cr	Cu	Zn	Ti	Al
1.05	0.80	0.68	0.26	0.01	0.04	0.02	0.01	Balance

Table 2. Monotonic properties of 6082-T6 aluminum alloy.

Tensile strength, σ_{uts} [MPa]	300±2.5
Yield strength, σ_{ys} [MPa]	245±2.7
Elongation, ε_r [%]	9

Fatigue tests were conducted, in agreement with ASTM E647 standard using Middle-Tension, M(T), specimens with 200 mm length, 50 mm width and 3 mm thickness. The specimens were obtained in the longitudinal transverse (LT) direction from a laminated plate. Fig. 1 illustrates the notch of the samples used in the tests. The notch preparation was made by electrical-discharge machining. After that, the specimen surfaces were mechanically polished.

All experiments were performed in a servo-hydraulic test machine interfaced to a computer for machine control and data acquisition. All tests were conducted in air, at room temperature and with a load frequency of 15 Hz. The specimens were clamped by hydraulic grips. The influence of the different loading sequences was investigated in the Paris regime at R=0.05. In all cases the crack growth rates were determined by the secant method.

During the single overload and load block tests the crack length was measured using a travelling microscope (45X) with a resolution of 10 μm. Collection of data was initiated after achieving an initial crack length of approximately 12 mm. The tests conducted under constant ΔK and stress ratio, R, conditions, were performed by manually shedding the