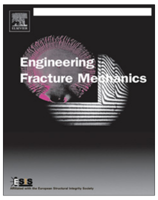
Engineering Fracture Mechanics 110 (2013) 489–500

Contents lists available at SciVerse ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech



Fracture resistance of aluminum multilayer composites

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ARTICLE INFO

Article history:
Available online 19 December 2012

Keywords:
Aluminum composite
Material inhomogeneity
Crack tip shielding
Fracture resistance

ABSTRACT

The so-called material inhomogeneity effect, which influences the crack driving force in inhomogeneous materials, has recently been found to contribute to the excellent behavior of some fracture resistant biomaterials. The current study aims to transfer these findings to engineering materials, by experimentally investigating the fracture behavior of multilayers consisting of a high-strength aluminum alloy and thin, soft polymer interlayers. Structures in crack divider and crack arrester (CA) configuration are tested. The results show that the structures in CA configuration exhibit a tremendously improved fracture resistance compared to the homogeneous bulk material. The reason is that cracks are completely arrested in the soft interlayers. This effect appears without delamination, i.e. it is basically different from the well-known delamination effect on weak interlayers.

1. Introduction

The heat-treatable Al–Zn–Mg–Cu (7xxx) alloys have the highest strength to weight ratio of all aluminum alloys, making them ideal candidates for lightweight constructions. Nevertheless, the application of these alloys in safety critical structures is limited due to their rather poor resistance to fracture and fatigue.

To overcome the dilemma that increasing strength leads to a toughness decrease in many materials and alloys, damage tolerant multilayered systems have been invented and intensively investigated in the past decades [1]. The basic idea behind these multilayered structures is to increase the fracture resistance by the delamination of weak interfaces, while at the same time preserving the high material strength [1–4]. Two configurations, denominated as crack divider (CD) and crack arrester (CA) configuration, are examined in these publications. In the CD configuration the crack plane is normal to the layers and the crack propagates through all layers at once (Fig. 1a), while in the CA configuration the crack also propagates perpendicular to, yet sequentially through the layers (Fig. 1b).

In the first works on the subject, metal/metal multilayer systems with weak interlayers, introduced by soldering, explosion-cladding, or roll-bonding, were investigated with respect to their impact toughness [3] or fracture toughness [4]. Compared to a homogeneous material of the same total thickness, the fracture behavior was improved in both configurations. This fact has been attributed to the delamination of the weak interfaces in the multilayers. The delamination diminishes the hydrostatic stress state around the crack tip, which leads to a retardation of void-initiation [5] and a reduction of the void growth rates [6] and, therefore, to an increased fracture toughness. Additionally, in the CA configuration the crack tip is blunted when it grows into the delaminated area, and a re-initiation of the crack is necessary for further crack growth.

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0013-7944/$ - see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.engfracmech.2012.11.007

Nomenclature

a	crack length
a_0	initial crack length
Δa	crack extension
A_{pl}	plastic area under the load vs. load-line-displacement curve
A_{el}	elastic work
A_{tot}	total area under the load vs. load-line-displacement curve
b	ligament length
b_{arr}	ligament length after crack arrest
B	specimen thickness
C_{inh}	material inhomogeneity term
E	Young's modulus
F	applied load
$F_{\max}$	maximum load reached in the fracture mechanics test
H	gauge length
J	J-integral
J_{el}	elastic component of the J-integral
J_{pl}	plastic component of the J-integral
J_{tip}	near-tip J-integral
J_{far}	far-field J-integral
$J_{\max}$	maximum J-integral
$J_{F_{\max}}$	J-integral value at $F_{\max}$
J_{IC}	fracture toughness in terms of the J-integral
J_{c}	fracture initiation toughness in the CA configuration
K	stress intensity factor
K_{JC}	critical stress intensity factor calculated from J_{IC}
L	length plastically deformed in the fracture mechanics specimen
n	strain hardening exponent
N_{u}	number of undamaged layers
$r_{\mathrm{y}}^{(\mathrm{pl}\sigma)}$	plastic zone radius in plane stress
R	crack growth resistance
$R_{\mathrm{p0.2}}$	yield strength
R_{m}	ultimate tensile strength
t	layer thickness
t_{opt}	optimum layer thickness
v_{LL}	load-line-displacement curve
V	volume plastically deformed in the fracture mechanics specimen
W	specimen width
γ	nondimensional factor to account for crack growth effects on J
Γ	surface energy needed to create new fracture surfaces
ε	engineering strain
ε^*	critical total strain
ε_{F}	engineering fracture strain
ε_{U}	uniform elongation
η^*	nondimensional factor connecting A_{pl} to J_{pl}
η	nondimensional factor connecting A_{tot} to J
ν	Poisson's ratio
σ	engineering stress
$\sigma_{\max}$	maximum nominal stress in the ligament after crack arrest
CA	crack arrester configuration
CD	crack divider configuration
COD	crack tip opening displacement
C(T)	compact specimen
SE(T)	single edge notch tension specimen

Similar observations have been made in laminates where metal layers were combined with polymer adhesives [7,8]. A recent development of these polymer/metal multilayers are fiber metal laminates, where the polymer adhesives are reinforced by glass- or aramid fibers [9,10]. The fibers bridge the zone behind the crack tip if the crack grows into the polymer, which should lead to a further improvement of the fracture behavior of the laminate.