18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 134–135
Paper #300

FATIGUE CRACK GROWTH AND DELAMINATION IN FIBER METAL LAMINATE (GLARE) DURING LOADING WITH POSITIVE MEAN STRESS

A. Chlupová[*], V. Kozák[**]

Abstract: *The aim of the paper is to present the results of a study on the damage of fiber metal laminate (GLARE) subjected to the low cycle fatigue loading with positive mean stress. The fatigue crack initiation and growth was observed on the surface of notched specimens and then the individual layers of fatigued specimens were removed by chemical etching and polishing to obtain data about cracks length and delamination shape and area. Mechanism of initiation and crack growth in this type of materials differs from homogeneous monolithic materials. The fatigue life in term of number of cycles to crack initiation depending on amplitude of local plastic deformation and local stress in the notch root was evaluated.*

Keywords: ***Fatigue, laminate, crack initiation, crack growth, delamination***

1. Introduction

The aim of this work is to present results obtained at study of fatigue properties of fibre metal laminates (FMLs). Material consisting of glass fibre reinforced plastic layers alternating with sheets of aluminium alloy 2024-T3 exhibits, contrary to the monolithic metal materials, longer fatigue life and extremely elongated stadium of fatigue crack propagation which makes this material safer and convenient for damage tolerant design of structural parts. The concept of this type of hybrid materials was developed at Delft University of Technology in Netherlands (Roebroeks 1991, Prasilova 1998) primary for aviation applications as is confirmed in (Vasek 1999, Chlupova et al. 2001) and presently it is used for example as a fuselage of Airbus A380 (Sinke 2006). Flat specimens made of GLARE 2 with unidirectional orientation of fibre reinforcement with three different thicknesses, provided with three kinds of notches with different stress concentration factor were subjected to cyclic loading with positive mean stress with parameter of asymmetry R = 0.04. Maximum applied stress in cycle σ_{max} was selected from 90 to 450 MPa. Fatigue crack initiation and growth on the surface of notched specimens was observed using microscope equipped with CCD camera. Loading was terminated at given crack length and after test termination the destructive analysis was performed to obtain data about level of material degradation (cracks and delaminations) inside of laminate.

2. Results and discussion

Mechanism of initiation and crack propagation: It was found that FMLs exhibit different mechanism of initiation and growth of fatigue cracks than homogeneous monolithic metallic materials. Cracks initiate first in metal layers inside of laminate. The crack front in FMLs is not continuous, it is created by crack fronts in individual layers laying usually not in one plane and with the maximum length on the surface of specimen. It is different than in case of crack front in monolithic metal materials where the crack front is continuous, in one plane and curved with maximum length inside of material. Prepreg thus acts as an effective barrier against crack growth from one layer to another and cracks grow separately and independently. FMLs exhibit shorter period of crack initiation but strongly elongated period of crack growth. Number of cracks initiated from the notch is higher and the place is transferred out of the root of notch. The deflection angle of crack initiation place is connected to: 1)

[*] Ing. Alice Chlupová, Ph.D.: Institute of Physics of Materials, Academy of Sciences of the Czech Republic, Žižkova 22; 616 62, Brno; CZ, e-mail: prasil@ipm.cz

[**] Ing. Vladislav Kozák, CSc.: Institute of Physics of Materials, Academy of Sciences of the Czech Republic, Žižkova 22; 616 62, Brno; CZ, e-mail: kozak@ipm.cz

fibre structure with intact fibres directly in the notch root which prevent crack initiation and 2) cut fibres acting as defects are situated at certain angle. These factors together with shift of maximum shear stress outside the notch root make the initiation directly in the notch root less probable.

Fatigue life expressed in form of dependences of number of cycles to crack initiation N_{in} and to elongation to defined length N_f was evaluated. Effect of applied stress level was assessed. Measured data were then used for finite element method calculation of local plastic deformation in the notch root ε_{pl}. Elasto-plastic behaviour and internal residual stresses in metal layers of laminate were taken into account. Relations for prediction of N_{in} and N_f of notched specimens from laminate were specified. The dependence of N_{in} on amplitude of local plastic deformation and/or local stress in the notch root of metal layers was evaluated. Amplitude of local plastic deformation in notch root can be considered as a parameter determining number of cycles to fatigue crack initiation in notched specimens from material GLARE.

Local plastic deformation in the notch root is induced by local stress σ_{peak}. The value of local stress can be calculated using maximum applied stress σ_{max}, stress concentration factor in metal layers $K_{t,Al}$ and internal residual stress in metal layers $\sigma_{r,Al}$. Dependence of N_{in} on calculated local peak stress for different thicknesses and different notch factors can be approximated by a power function. The relationship between N_{in} and values of $K_{t,Al}$, $\sigma_{r,Al}$ and σ_{max} explains experimentally obtained shorter time to crack initiation for thicker laminates.

Delamination area having nearly elliptical shape is proportional to crack length which induced it. As soon as the crack in metal layer is initiated simultaneously the delamination appears as a result of shear stresses on interface between layers. The size of delamination is affected by many factors such as crack length, crack growth rate, fibres properties and fibres volume fraction but predominantly on quality of adhesion on interface, i.e. on shear stresses at metal-prepreg interface. The proper function of laminate, i.e. bridging effect of reinforcing fibres on growing crack resulting in outstanding fatigue resistance can be assured only by optimum strength of adhesion on metal-prepreg interface which causes suitable range of delamination. A judgement of effect of adhesion quality is difficult due to its antagonistic influence on delamination size. Strong adhesion results in small delamination. In the extreme: at no delamination the length of fibres actively acting on crack closure would be so small that crack wouldn't open and crack would stop. On the other hand at these conditions the loading of short part of fibres would be so enormous that it would cause the failure of fibres. The right function of fibres and their bridging effect wouldn't be thus possible. Weak adhesion results in big delamination and significant decrease of bearing capacity. In the extreme: it would cause debonding of laminate along the fibre-matrix interface. In that case the transfer of loading through shear stresses from metal to prepreg layers and vice versa wouldn't be possible. The delamination for both types of material (GLARE2 and GLARE 3) was found to be dependent on the level of maximum applied stress and also on location in metal-prepreg interface closer or further from the specimen surface.

Acknowledgement

Financial support of projects GACR 106/09/1954 and RVO 68081723 is acknowledged.

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