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Experimental verification of thickness effects on fatigue crack growth in an AA 7475 plate

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Abstract. Fatigue crack propagation behaviours under constant and variable amplitude loading while taking into account thickness effects is investigated. A plate aluminium alloy 7475 T351 with a thickness of 76 mm is analysed. Thicknesses of 2 to 8 mm are examined. The significant differences between fatigue crack behaviours under constant and variable amplitude loading are defined. While different thicknesses have no significant effects under constant amplitude loading, significant differences are identifiable in cases of variable amplitude loading. A thickness of 2 mm results in a 2.6-fold longer lifetime compared to the lifetime corresponding to a thickness of 8 mm.

Introduction

Fatigue crack propagation in metals has generally been quantified in terms of stress intensity factors. The magnitude of higher order terms in the near-tip asymptotic elastic stress field is dependent on geometric features. It has been found experimentally that a fatigue crack can remain closed for part of the fatigue cycle and in cases of tensile-tensile loading. The portion of the fatigue cycle for which the crack is open provides the driving force for crack growth. Closure ratios have been defined for various alloys in consideration of constant amplitude loading. Based on this knowledge, different analytic and numerical models have been derived. Prediction models are based on crack closure phenomena and stress-strain condition development in the area surrounding a crack tip. The most well-known models used in aerospace include the following: Willenborg, Wheller, ONERA, CORPUS, AFGROW and NASGRO ([1]-[5]). All of these models consider material characteristics evaluated under constant amplitude loading. The parameters of prediction models are usually defined through experiments conducted under variable amplitude loading.

The new concept of an airframe structure has been adopted throughout the development of new versions of the L-410 commuter aircraft. Integral panels are used in the airframe structure. These thin curvature panels are composed of thick plates that are milled to thin parts with integrated stiffeners referred to as stringers [6]. Unfortunately, some significant discrepancies between actual and predicted fatigue crack propagation patterns under variable amplitude loading conditions have been identified [7]. Several works have focused on the enhancement and verification of prediction tools [6 - 10]. All of these studies confirm problematic propensities for current models to describe thickness changes via standard procedures.

This paper describes an experimental investigation of fatigue crack propagation behaviours under constant and variable amplitude loading conditions while taking into account thickness effects on 7475 T351 aluminium alloys. The aim of this work was to address the following questions:

- Do thick specimens composed of thick plates affect the material characteristics defined under constant amplitude loading conditions?
- Do specimens composed of thick plates affect fatigue crack propagation behaviours under variable amplitude loading conditions?

Material and specimen configuration

An ALCOA 7475 T7351 plate material was experimentally studied as a typical structure material used in L410NG airframes. Plate semi products with a nominal thickness of 76 mm were used. During airframe manufacturing, 76 mm-thick plate materials were machined into final products of different thicknesses (of typically 2 to 8 mm). This paper thus only considers data for this typical thickness range. Two extreme thicknesses of 8 and 2 mm were examined under constant amplitude loading to answer the first question listed above. Three nominal thicknesses of 2, 4 and 8 mm were examined under variable amplitude loading conditions.

The M(T) specimens shown in Fig. 1 were used for the crack propagation investigation. A specimen width of 100 mm was applied.

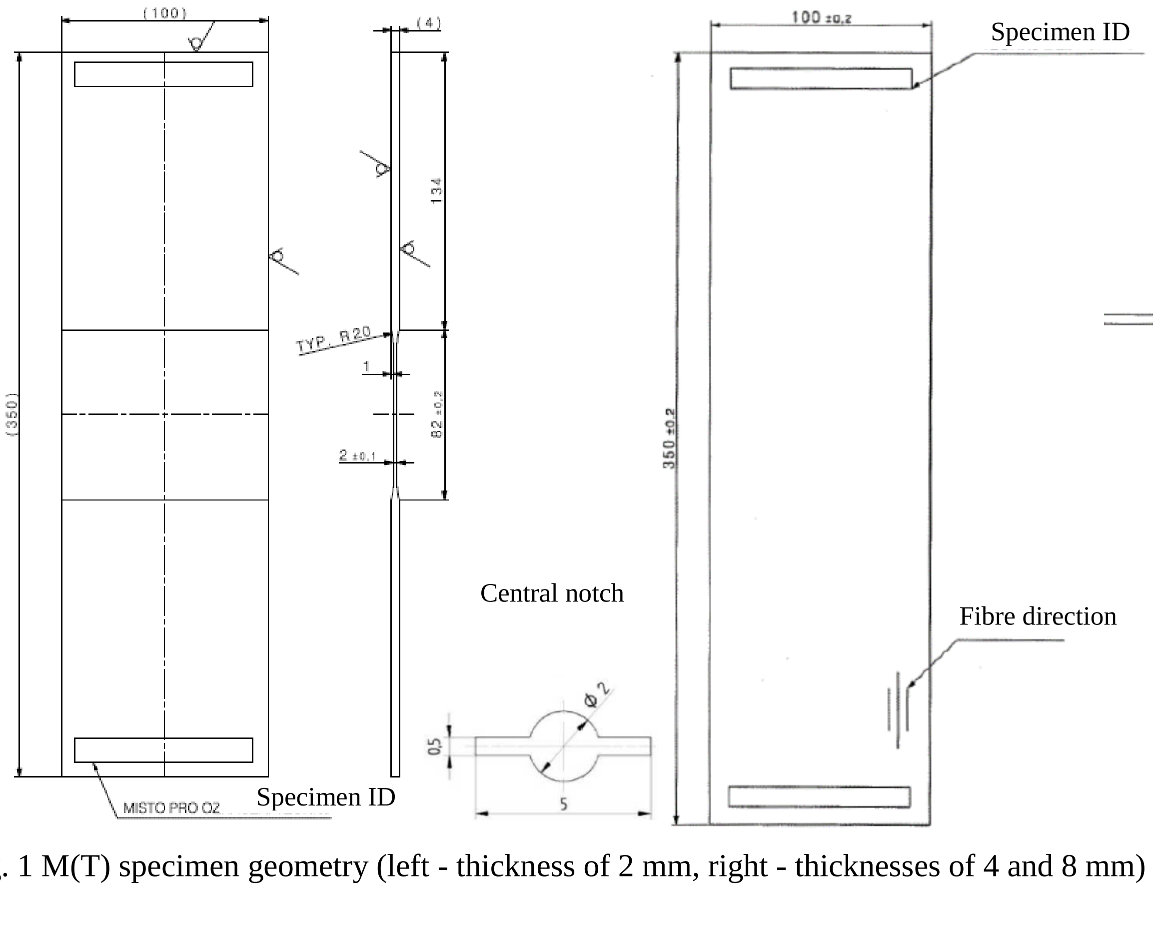

Fig. 1 M(T) specimen geometry (left - thickness of 2 mm, right - thicknesses of 4 and 8 mm)

Test and loading conditions description

Fatigue crack growth tests were conducted using a hydraulic SCHENCK load frame with a capacity of 250 kN. The SCHENCK load frame was controlled by the INSTRON FastTrack 8800 test control system. It provides real-time closed loop control, including transducer conditioning and function generation. Specimens were clamped into the hydraulic test frame with mechanical grips. The test set up, i.e., the M(T) specimen, load frame, mechanical grips and microscopes, is shown in Fig. 2.

Fig. 2M(T) fatigue crack growth test configuration

The test procedure was conducted in agreement with ASTM E-647 standard requirements [20]. Fatigue crack initiation and propagation were monitored via a visual method (VT) using an Olympus SZ40 light stereomicroscope with a maximum magnification of 40x. Crack length measurements were carried out on both surfaces and sides relative to the longitudinal axes of the specimens.

A harmonic loading (sinusoidal load cycle) with a constant force amplitude was used in the crack initiation phase. The effects of thickness were studied for the constant and variable (randomized flight-by-flight sequence) amplitude loading. A harmonic loading (sinusoidal load cycle) with a constant force amplitude and stress ratio of 0.05 was used for basic material characteristic definition. A typical randomized flight-by-flight sequence with a variable amplitude representative of the wing of a small SQ_0060 commuter aircraft was used. The sequence consists of 3,000 flights and represents stress spectra of an L 410 NG airplane bottom wing surface panel skin in section 21. The SQ_0060 loading sequence contains 174.975 cycles. One flight corresponds to 1 flight hour.

Experimental results and discussion

Basic fatigue crack growth material characteristics of the plate material were defined using 8 mm thick specimens. These material characteristics have been used as a basis for crack growth predictions generally. Figs. 3 and 4 compare data obtained under the constant amplitude loading (specimen thickness of 8 vs. 2 mm). Fig. 3 compares the crack rate vs. effective stress intensity factor data for the 8 mm thick specimens (data includes three different stress ratios (R = 0.02, 0.2 and 0.6)) with those of the 2 mm thick specimens (stress ratio of 0.02). The effective stress intensity factor was calculated using the Schijve equation [5]. The crack growth data measured for the 2 mm specimens overlap with data obtained on the 8 mm specimens. The 2 mm thickness data shown in the upper scatter data range of the 8 mm thickness data in terms of crack growth rates range between 10^{-8} and 10-^{7} mm.cycle^{-1}. This implies that the crack propagation data corresponding to a thickness of 2 mm are faster than those of the 8 mm data under the same loading conditions. This finding is illustrated in Fig. 4. Fig. 4 also shows scatter data for two 8 mm specimens loaded under the same loading conditions. Relatively high scatter levels in crack growth data under constant amplitude loading conditions are shown (±15%). It is recommended that data scatter results are confirmed and analysed using a larger number of specimens.

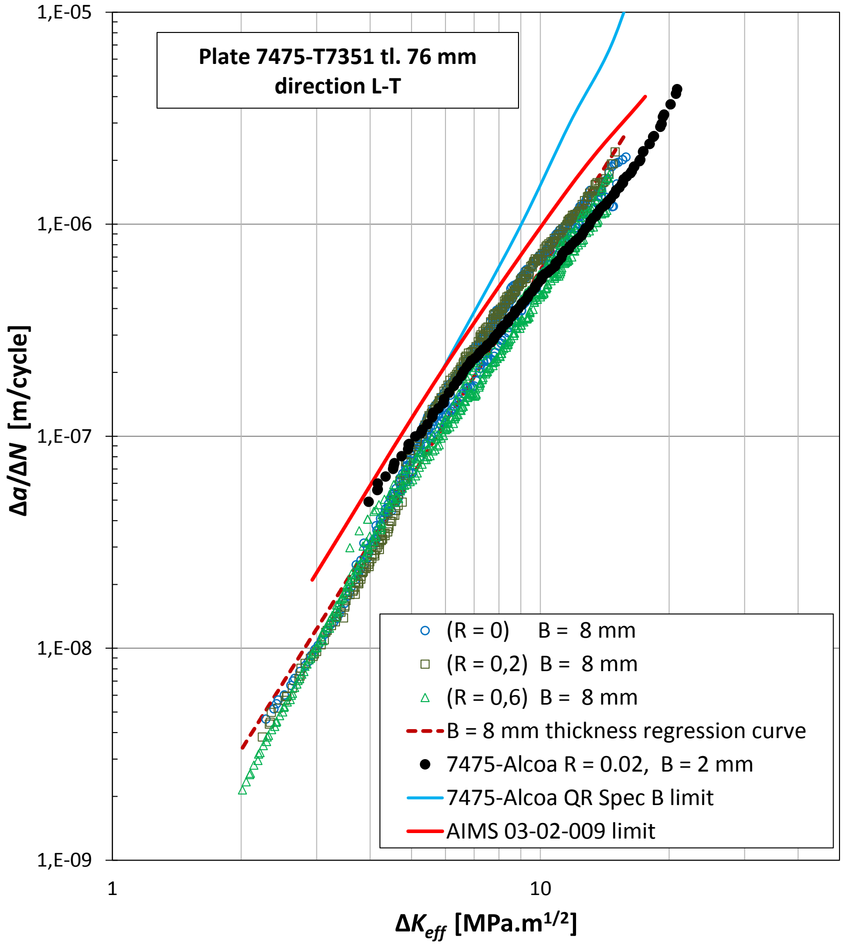

Fig. 3 7475 T7351 crack rate vs. effective stress intensity factor data – effect of thickness

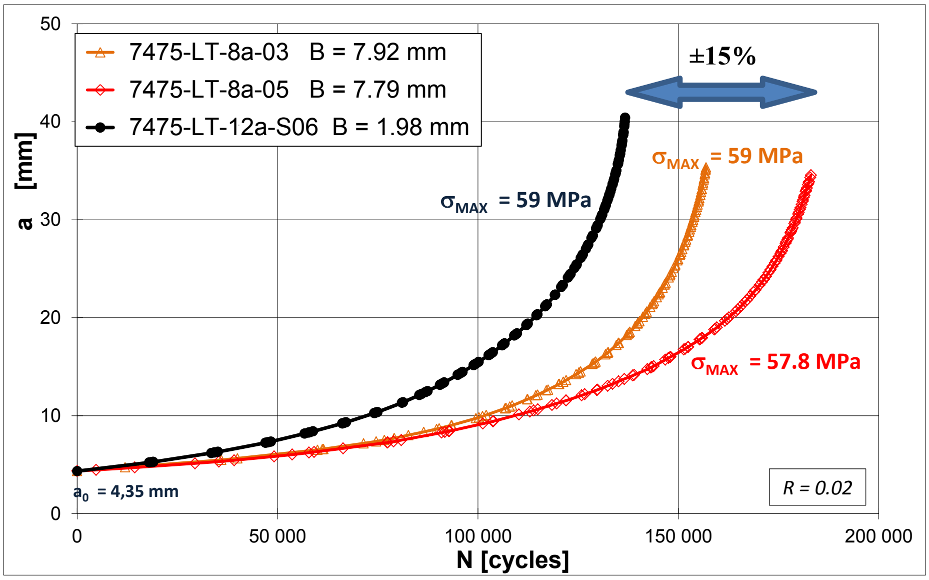

Fig. 4 7475 T7351 crack propagation data under constant amplitude loading – effect of thickness

Figs. 5 presents fatigue crack propagation data measured for the three different thicknesses (2, 4 and 8 mm) under variable amplitude loading. All of the specimens were loaded using the same stress loading parameters – the maximum stress value in the sequence of 89 MPa. Thickness effects on crack propagation behaviours are evident. A thickness of 8 mm gives the shortest crack propagation lifetime while a thickness of 2 mm gives the longest crack propagation lifetime. This difference is significant. A thickness of 2 mm results in a 2.6-fold longer lifetime than that corresponding to a thickness of 8 mm. This difference cannot be explained by the presence of potential differences in basic material characterisation data alone. Moreover, the material data under constant amplitude loading show the opposite relationship. Significant changes in crack propagation mechanisms associated with plane stress states, plane strain states and transition modes between both states must be taken into account in prediction models. This may explain why no present prediction model is able to predict this feature. Further data on shear lip development patterns are therefore necessary for this feature's description. Additional experimental and numerical research must therefore be conducted to fully understand the effects of thickness levels on fatigue crack propagation behaviour.

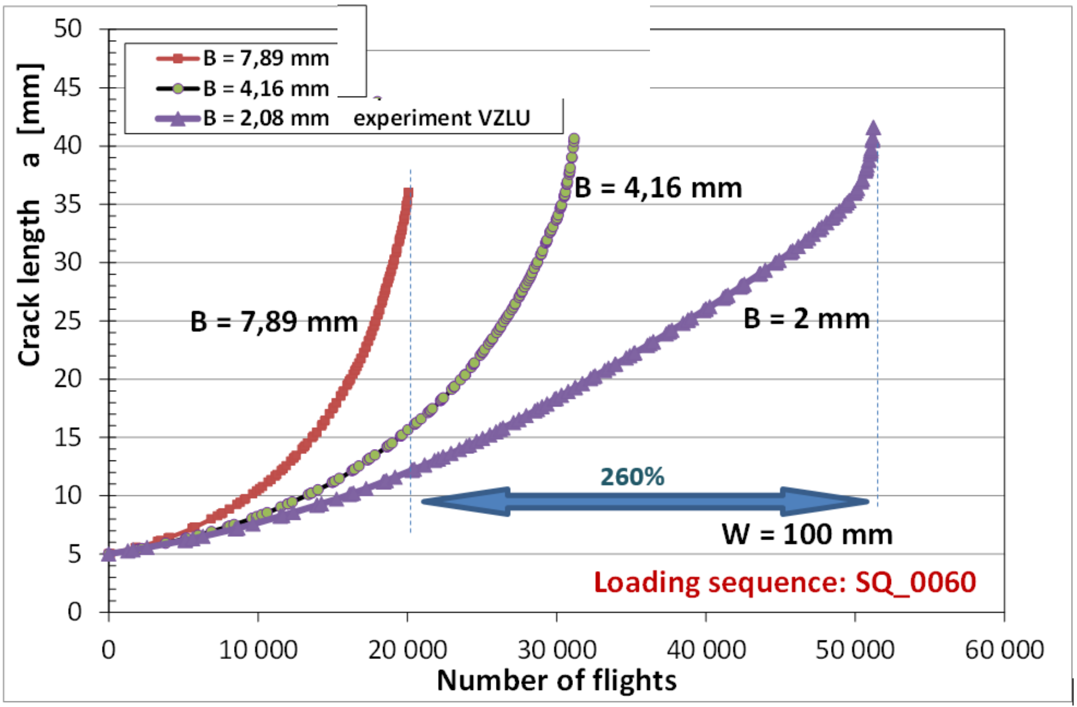

Fig. 5 7475 T7351crack propagation data comparisons under variable amplitude loading conditions σ_{max} = 89 MPa – effect of thickness

Conclusions

This paper focuses on an experimental investigation of fatigue crack propagation behaviours under constant and variable amplitude loading conditions that considers the effects of thickness on ALCOA 7475 T351 aluminium alloy.

Thickness effects were studied under constant and variable amplitude loading conditions. We studied 7475 T7351 plate materials with a nominal thickness of 76 mm. Three final machined thicknesses of 2 to 8 mm were examined. A significant difference between fatigue crack behaviours under constant and variable amplitude loading conditions was found. While different thicknesses had no significant effect under conditions of constant amplitude loading, significant differences were found in cases of variable amplitude loading. This implies that the existing prediction models are not able to predict crack propagation patterns solely based on material characteristics defined under constant amplitude loading conditions without defining additional model parameters.

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References

[1] J.G. Willenborg, R.M. Engle, H.A. Wood: A crack growth retardation model using an effective stress concept. AFFDL-TM-71-1 FBR, Air Force Flight Dynamics Lab. (1971).

[2] D. Aliaga, A. Davy, H. Schaff: A simple crack closure model for predicting fatigue crack growth under flight-simulation loading. ASTM STP-982, American Society for testing and material, (1988) pp.491-504.

[3] A.U. DeKoning: A simple crack closure model for prediction of fatigue growth rates under variable-amplitude loading. ASTM STP-743 (1981) pp.63-85.

[4] U.H. Padmadinata, J. Schijve, Prediction of fatigue crack growth under flight-simulation loading with the modified CORPUS model, Report LR-760, Delft University of Technology, the Netherlands (1994).

[5] R. Růžek: Fatigue crack growth in aerospace structures under complex loading conditions. Doctoral dissertation, Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering, Prague (1993).

[6] J. Šedek, R. Růžek, J. Raška, J. Běhal: Comparative study of prediction methods for fatigue life evaluation of an integral skin-stringer panel under variable amplitude loading. Procedia Engineering, 114 (2015) pp.124 – 131, doi: 10.1016/j.proeng.2015.08.050

[7] J. Běhal: Comparison of crack growth prediction models implemented into the AFGROW software. Technical report R-6592, VZLÚ, Praha (2016).

[8] J. Běhal, P. Homola, R. Růžek.: Effect fracture resistance on retardation of crack growth. International Journal of Structural Integrity, Vol. 6 No. 4 (2015) pp.1-13, doi: 10.1108/IJSI-10-2014-0053

[9] J. Běhal, P. Homola,: Simulation of Operational Loading Spectrum and its Effect on Fatigue Crack Growth, Procedia Engineering 101 (2015) pp.26-33, doi: 10.1016/j.proeng.2015.02.005

[10] J. Běhal, L. Nováková: Stress state factor evaluation based on fractographic analysis for use in crack growth FASTRAN retardation model of AFGROW computing code, Engineering Failure Analysis, Vol. 35 (2013), pp.645-651, doi:10.1016/j.engfailanal.2013.06.014