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Experimental Verification of Thickness Effect on Fatigue Crack Growth in AA 2124 Plate

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Abstract. Both predictions and experimental results indicate for some materials significant discrepancies between crack propagation data of machined parts from a thick plate to different thinner thicknesses. The different fatigue crack growth behavior under constant and variable amplitude loading can be recognized. The thickness influence could be one of the main possible reasons for this unexpected behavior. The paper deals with a plate thickness of 50 mm made from 2124 T851 aluminum alloy. Crack propagation was investigated for various specimen thicknesses and different loading conditions. No significant thickness influence on the crack propagation behavior occurred both for constant and variable amplitude loading typical for a commuter aircraft loading spectra. It implies that present prediction models are able to predict the crack propagation in this material only using basic material characteristics defined under the constant amplitude loading.

Introduction

Fatigue crack propagation in metals is generally quantified in terms of stress intensity factor. Based on previous knowledge, different analytic and numerical models were derived. Various prediction models are based on the crack closure phenomenon and/or stress-strain conditions development in the surrounding area of the crack tip. All the models consider the material characteristics evaluated under the constant amplitude loading. Parameters of the prediction models are usually defined by means of experiments under constant and variable amplitude loading. Thin-walled structures made from sheets and various profiles without additional significant thickness reduction had been used in the aerospace industry in the past. Then the thickness influence is not so critical for these structures. The prediction models in this case could evaluate the fatigue crack propagation trends very well. In case of a significant thickness reduction of a plate material, standard prediction models could lead to misguided results or huge experimental work have to be performed ([1]-[4]).

Several works focused on damage tolerance investigation of metallic airframe structures were carried out in the framework of „The advanced aerostructure research centrum“, project no. TA0200003. Within this project, the crack propagation predictions based on analytical models indicated some significant discrepancies as compared with experimental results based on variable amplitude loading using randomized flight-by-flight loading sequences. These unexpected results invoked the request to perform more detailed investigations to experimentally clarify the real crack growth behavior for different thicknesses of final parts manufactured from a plate material.

The thickness influence on fatigue crack growth under constant and variable amplitude loading of AA (aluminum alloy) 7475 plate material was proved previously [5]. Significant differences between constant and variable amplitude crack growth data were found out. While crack propagation data under constant amplitude loading did not indicate any potential thickness influence, the fatigue crack propagation data obtained under variable amplitude loading showed a significant thickness influence. Thickness of 8 mm had significantly shorter crack propagation lifetime as compared with thickness of 2 mm. Thickness of 2 mm showed in about 260% longer lifetime as compare to thickness of 8 mm.

The paper documents experimental research work focused on the thickness influence investigation on crack propagation behavior of AA 2124-T851 aluminum alloy plate material under constant and variable amplitude loading spectrum representing a commuter aircraft service.

Material and specimen configuration

2124 T851 plate material (manufacturer KUMZ in Russia) was experimentally investigated as a typical airframe structural material. A plate semi product with nominal thickness of 80 mm was used. During a structure part manufacturing the plate is machined into the final varying thickness (typically from 2 up to 8 mm). Therefore, the paper consider just the data within this typical thickness range. Two extreme thicknesses of 8 and 2 mm were investigated in case of the constant amplitude loading and three nominal thicknesses of 2 mm, 4 mm and 8 mm were investigated in case of the variable amplitude loading.

Typical M(T) specimens shown in Fig. 1 were used for the crack propagation investigation. Specimen width of 100 mm was selected. The same notch shape in the critical part (middle part with the crack starter) was made in all the specimens, see Det. A in Fig. 1.

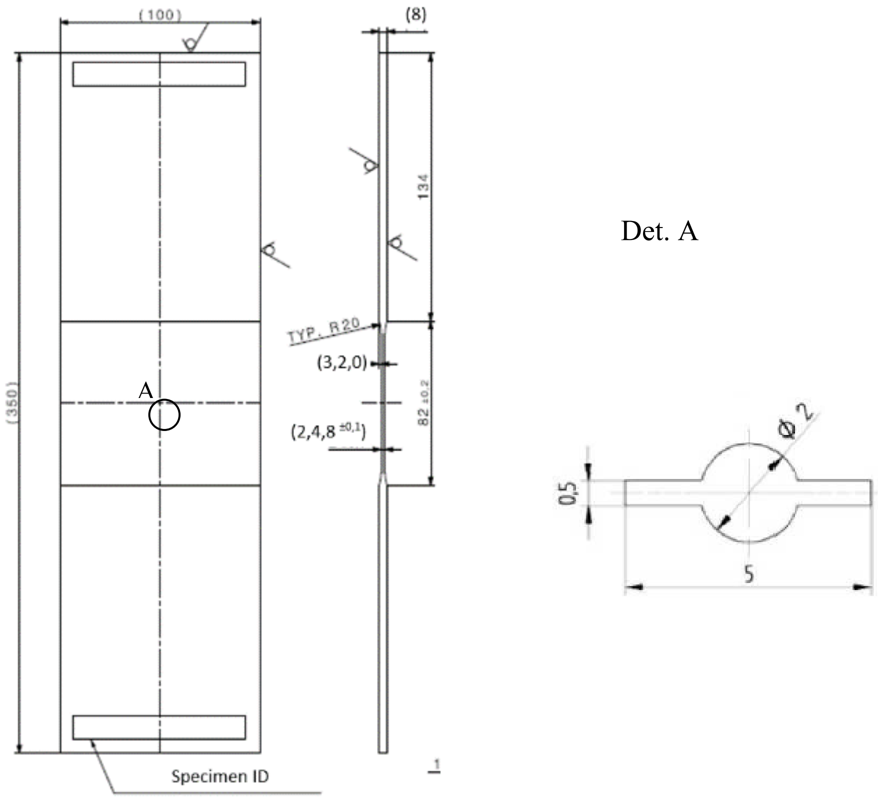

Fig.1 M(T) specimens geometry

Test methods

Fatigue crack growth tests were conducted using hydraulic SCHENCK load frame with capacity of 250 kN. The SCHENCK load frame was controlled by the INSTRON FastTrack 8800 test control system. Specimens were clamped into the hydraulic test frame through mechanical grips. Test set-up, i.e., M(T) specimen, load frame, mechanical grips and microscopes, is shown in Fig. 2.

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

Test procedure was divided into two steps. Main goal of the first step was crack initiation. The aim of the second one was the crack propagation monitoring. The pre-cracking procedure was always conducted under constant amplitude loading; the crack propagation phase was conducted under either constant or variable amplitude loading. The test procedure was performed in agreement with ASTM E-647 standard requirements [6].

Fatigue crack initiation and propagation was monitored by visual method (VT) using light stereomicroscopes Olympus SZ40 with maximum magnification of 40x. The crack length measurement was carried out on both surfaces and both sides regarding to the longitudinal axis of the specimens.

A harmonic loading (sinusoidal load cycle) with constant force amplitude was used in the crack initiation phase. The thickness influence was investigated for both constant and variable (randomized flight-by-flight sequence) amplitude loading. A typical randomized flight-by-flight sequence with variable amplitude representative for a wing of small commuter aircraft called SQ_0058 was used. The sequence consists of 3000 flights and represents stress spectra of a bottom wing panel skin surface. The SQ_0058 loading sequence contains total number of 166.302 cycles. Fig. 3 illustrates a part of the sequence in a graphical form.

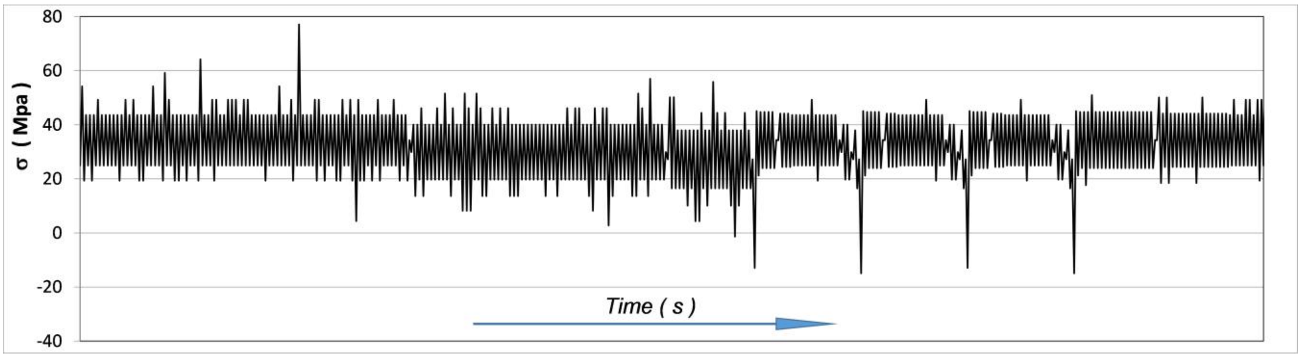

Fig.3 Visualization of a typical segment from flight-by-flight loading sequence

Experimental results and discussion

Basic fatigue crack growth material characteristics of the plate material of 50 mm in thickness were defined using specimens with thickness of 8 and 2 mm. No significant difference was found out. Maximal difference between crack growth lifetimes under similar stress conditions was ±13% of elapsed numbers of cycles. This difference is in very good compliance with the previous experience [5], [7], [8]. Fig. 4 compares data obtained under the constant amplitude loading (specimen thickness of 8 vs. 2 mm) including data from previous experiments. No significant thickness and plate material influence was found out.

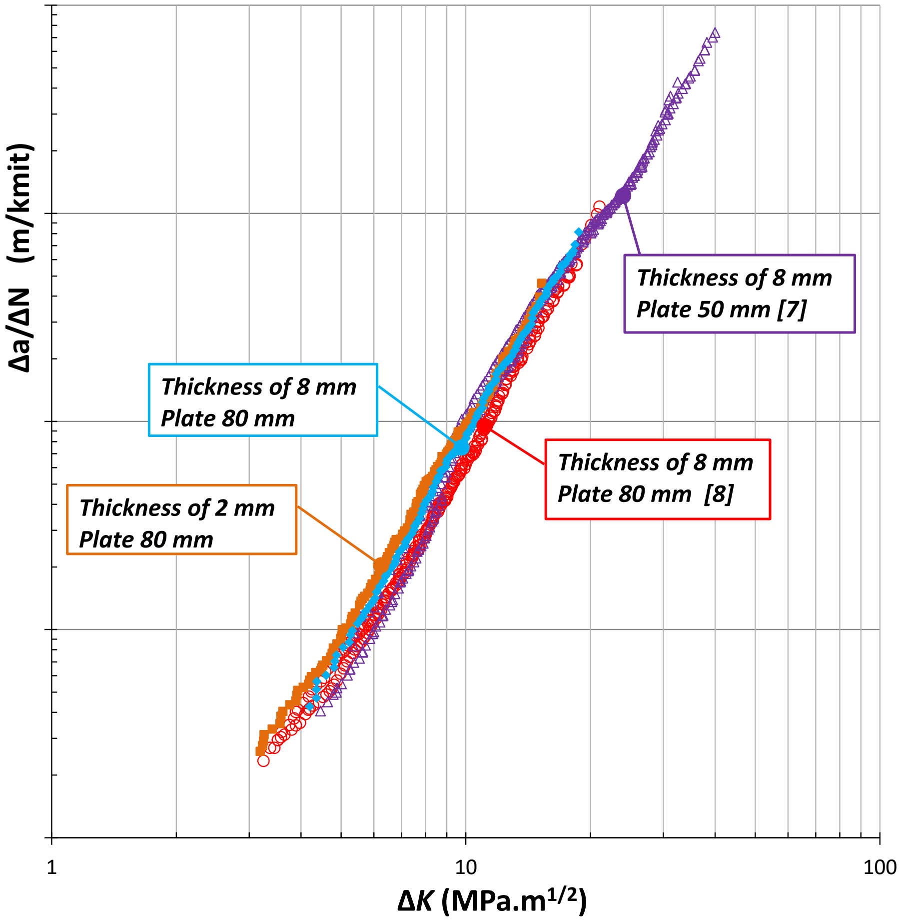

Fig.4 2124-T851 crack rate vs. effective stress intensity factor data – thickness influence

Fig. 5 documents fatigue crack propagation data measured for different thicknesses (2, 4 and 8 mm) under variable amplitude loading. All the specimens were loaded using the same stress loading parameters – loading sequence of SQ_0058 with maximum stress value in the sequence of 79.6 MPa. No thickness influence on the crack propagation was observed.

The results imply the conclusion that present prediction models are able to predict the crack propagation in investigated 2124 T851 plate only using the material characteristics defined under the constant amplitude loading without definition of additional parameters into the models. The results confirmed that various aluminium alloys have a significantly different behaviour from damage tolerance properties viewpoint ([1-8]). The selection of parameters in prediction models have to be a critical point of inspection intervals designing.

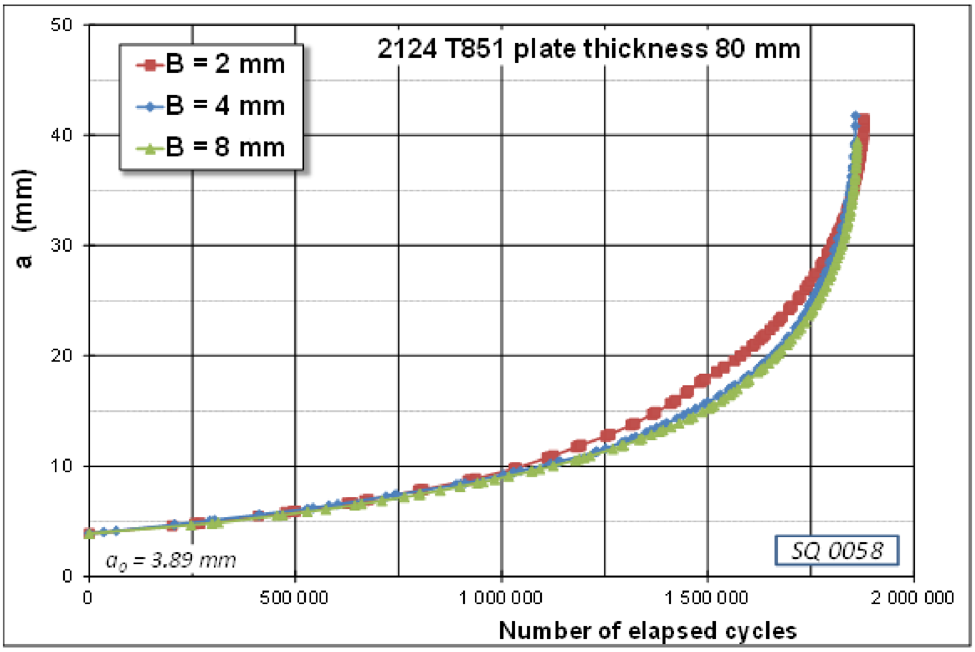

Fig.5 2124-T851 – crack propagation data comparison under variable amplitude loading (σ_{max} = 79.57 MPa)

Conclusions

Constant amplitude loading:

- All the data in range of thicknesses from 2 mm up to 8 mm lies in the same group of data represented by using of stress intensity factor.
- The data of the tested specimens shows difference scatter of ± 13 % between total crack propagation lives (development from the same initial crack length up to specimen failure). It can be considered as a good agreement from viewpoint of previous experience with similar characteristics.
- Data scatter ± 13 % is very similar to data scatter ± 15 % for 7475 T7351 data documented in [5] for the same thickness range (2 - 8 mm) data.

Variable amplitude loading:

- No thickness influence on the crack propagation behavior was proved.

AA 2124 and 7475 plate materials show different crack growth behavior, hence, it is very desirable to verify crack propagation behavior also for other aluminum alloys used in commuter airframe structures.

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