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A FATIGUE CHARACTERIZATION OF HONEYCOMB SANDWICH PANELS WITH A DEFECT

UTRUJENOSTNA KARAKTERIZACIJA SATASTIH SENDVIČNIH PANELOV Z NAPAKO

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Honeycomb sandwich panels are used because of their high stiffness, good fatigue resistance and low weight. These panels are used in a variety of applications, but particularly in the aerospace industry. When this is the case a simple knowledge of the static properties is not sufficient and additional information about the fatigue properties is required. In real situations these panels can be affected by manufacturing defects and impacts, and it is important to know the effects of these defects and the behaviour of the damaged panel; it also important to determine the location of the defect. In our investigation these defects will be simulated by a blind hole in the centre of the lower face sheet. Static and fatigue tests (four-point bending) with acoustic-emission monitoring were carried out on sandwich panels with defects. The load/displacement and the *S-N* fatigue curves are presented and analyzed.

Key words: sandwich, honeycomb, four-point bending, fatigue, defect, acoustic emission

Satasti sendvični paneli se odlikujejo po veliki togosti, dobri odpornosti proti utrujenosti in nizkem razmerju mase. Te panele se uporablja za različne namene, posebno v letalski industriji. V tem primeru ni dovolj poznanje statičnih lastnosti, zato so potrebne dodatne informacije o utrujenosti. Pri uporabi lahko na lastnosti panelov vplivajo napake pri izdelavi in poškodbe, zato je treba poznati učinek napak in razvoj poškodb, pa tudi znati določiti mesto poškodbe. Napake so v tem delu simulirane s slepo izvrtino v sredini spodnje površine panelne plošče.

Izvršeni so bili statični in utrujenostni preizkusi s štiritočkovnim upogibom z akustično emisijo na panelih z napako. Predstavljene in analizirane so odvisnosti obremenitev – pomik in utrujenostne krivulje S-N.

Ključne besede: sendvič, satje, 4-točkovni upogib, utrujenost, napaka, akustična emisija

1 INTRODUCTION

The main benefits of using the sandwich concept in structural components are the high stiffness, the good fatigue resistance and the low weight. Recent advances in materials and manufacturing techniques have resulted in further improvements and the increased uniformity of the properties of sandwich composites. In order to use these materials in different applications, a knowledge of their static properties alone is not sufficient, and additional information about their fatigue properties is required. However, many difficulties are encountered, mainly in forecasting their fatigue life, which reduce the utilisation of such materials in various industrial and aerospace applications.

Investigations of the bending-fatigue behaviour of sandwich beams were performed by Olsson and Lönnö [1], Echtermeyer et al. [2], Allen and Shenoi [3], Lagunegrand et al. [4], Burman and Zenkert [5]. It was found that under fatigue cycling of constant amplitude, the nucleation phase of fatigue damage extends over the major part of the fatigue life, while the phase of defect propagation is very short. The fatigue life of a component will also be adversely affected by damage, though the magnitude of this reduction in fatigue life is often more difficult to establish [6,7]. The fatigue of damaged (initial defects) structures may be determined by the extensive testing of specimens with various defects at different load levels [8].

Static overload or fatigue damage may cause significant degradation of the core or skin, which is not easily detectable by a visual inspection or conventional non-destructive evaluation techniques. Damage in a sandwich structure is not only caused by in-service loads; in the manufacturing processes used, defects within the sandwich, such as skin/core interface disbanding and stress concentrations at joints between core materials, can also occur [9,10].

Acoustic emission (AE) provides the possibility to monitor, dynamically in real time, the response to a discontinuity under an imposed structural stress, and has a significant advantage over other non-destructive testing methods. AE is a quality-control and non-destructive evaluation (NDE) technique that has proven to be most useful in metals and sandwich-composite structures [11,12]. Basically, AE employs a transducer, fixed to the structure, which registers emitted sounds from the loaded structure. The emitted sounds are then quantified and compared to a database of known sound-defect relationships, and the degree of damage from which the sounds are emitted can be quantified [13]. The analysis of the AE signals in the time and frequency domains can allow AE monitoring to be used to identify failure modes.

Attempts to correlate our results with those from other researchers are also complicated by the effect that acquisition parameters, such as filtering, threshold settings and sensor response, may have on the processed results. Of primary interest when performing mechanical testing utilising AE equipment, is the amount of activity (e.g. hits, events or counts), when it occurs (relative to load and/or time), where it originates (multiple sensor arrays allow location detection), and the characteristics of the signals in both the time and frequency domains. The signal amplitude is widely used as the first stage of damage characterisation. The main disadvantage of AE is that it requires a knowledge of the signal-propagation characteristics and a history of typical failures for the material and the structure under investigation. In practice it is common to determine experimentally the velocity by measuring the time taken by a known signal to travel a defined distance. The sound velocity in the sandwich panel was found to be approximately 2500 m/s [12,14].

To establish a robust fatigue-life model, a better understanding of the various failure mechanisms during cyclic loading is necessary. Fatigue tests (four-point bending) have been carried out on sandwich panels with and without a defect. To study the growth of the damage near the hole, AE was used, since it was expected that the different stages of the failure mode would be revealed. The expected result is a diminution of the remaining fatigue-life time, in proportion to the size of the hole.

2 MATERIAL AND EXPERIMENTAL TECHNIQUES

Sandwich panels consist of an aluminium core and a pure aluminium face sheet. The honeycomb core is an open cell with a density of 82 kg/m^3 of aluminium core. The cell size is 9.6 mm. The dimensions of these panels are shown in **Table 1**.

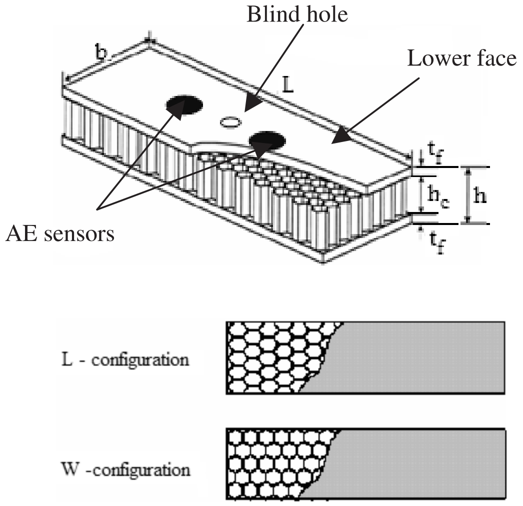


Figure 1: Honeycomb sandwich panel showing L and W configurations [15]

Slika1: Satasti sendivčni panel v L- in v W-konfiguraciji [15]

Table 1: Sample dimension

Tabela 1: Dimenzije preizkušanca

L (mm)	b mm	h mm	h_c (mm)	t_f mm	L_2 mm	L_1 mm
500	250	10	8.80	0.60	420	210

The skin material is AlMg$_3$ 5754. The properties of the core are shown in **Table 2** [15].

Table 2: Core mechanical properties

Tabela 2: Mehanske lastnosti jedra panela

Material	Aluminium – Aluminium
Core	ECM
Cell dimension /mm	6.4
Density /(kg/m^3)	82
Shearing Strength (configuration L) /MPa	2.4
Shearing Modulus (configuration L) /MPa	430
Shearing Strength (configuration W) /MPa	1.40
Shearing Modulus (configuration W) /MPa	220
Compression Strength /MPa	4.5

The beams with defects were tested with four-point bending and were monitored with AE, as shown in **Figures 1 and 2**. The tests were carried out with a servo-hydraulic Instron 8501 universal testing machine with a 10-KN capacity and a 2-mm/min crosshead velocity (**Figure 3**).

Cyclic flexural tests were also performed. The tests were carried out under load control at a load ratio R = 0.1 using a sinusoidal wave form. The beams were cycled at a frequency of 2 Hz. The fatigue data were generated at load levels of 100 %, 90 %, 80 %, 70 % and 60 % of the ultimate static load. The fatigue life of the specimens is defined as the number of cycles to ultimate failure. The normalised applied load is plotted against the number of cycles on a log-log scale.

The AE system used was a Vallens AMSY-5, data-acquisition unit with Vallens SE-45-type trans-

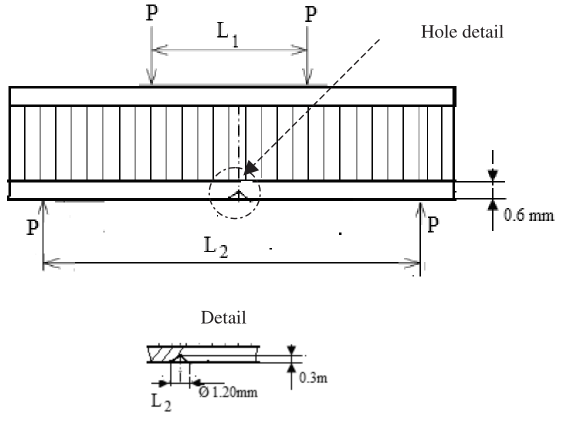


Figure 2: Schematic of sandwich beam for four-point bending and hole geometry

Slika2: Shema sendvične grede pri 4-točkovnem upogibu in geometrija izvrtine

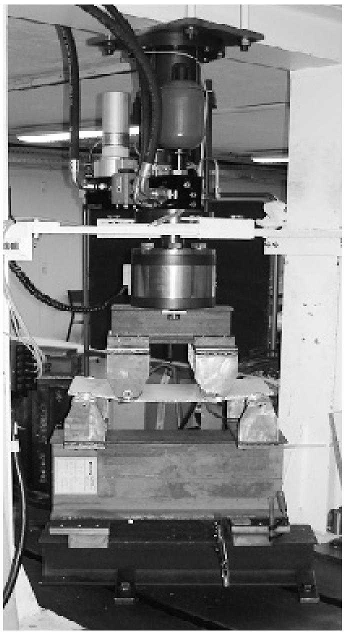


Figure 3: Test setup
Slika 3: Shema preizkusne naprave

ducers [16]. These sensors have sensitivity in the range 25 kHz to 120 kHz and a secondary range of sensitivity from 120 kHz to approximately 450 kHz. The AE signal was band-pass filtered with a 30 kHz to 1 MHz preamplifier and the total system amplification maintained at 40 dB allowed processing of the preamplifier input signal up to 99.9 dB above 1 mV (±99 mV peak). The AE sensors were mounted directly on the lower skin without any preparation of the contact surface using petroleum jelly as the acoustic coupling. The contact pressure was maintained with elastic tape.

3 RESULTS AND DISCUSSION

3.1 Static tests

AE was used to detect the damage and the crack mechanisms in the structure. **Figures 4 to 5** show the applied load vs. the displacement. However, the same observation can be made with the energy or the amplitude of the events. The same test had already been performed on the same sample, but without a defect [10].

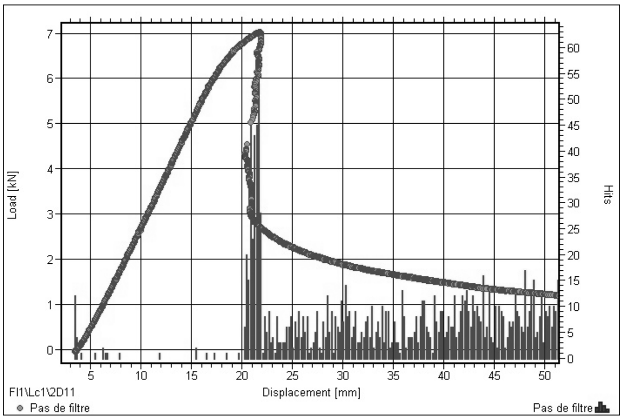


Figure 4: Load-deflexion Alu-Alu direction W
Slika 4: Obremenitev upogiba Alu-Alu v smeri W

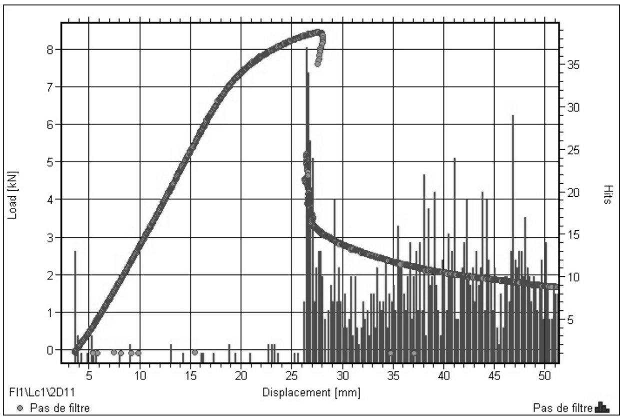


Figure 5: Load-deflexion Alu-Alu direction L
Slika 5: Obremenitev upogiba Alu-Alu v smeri L

We observed that the sandwich structures present a maximum ultimate load and exhibit ductile behaviour. The material shows more resistance in the L than in the W cell configuration (**Figures 4 and 5**). At the beginning of the plasticity domain, and during the catastrophic failure, there is intense AE activity. Moreover, the hole does not have an influence on the static behaviour of the honeycomb sandwich panels. The modes of collapse were identified: the face yield, the cell buckling, and the indentation beneath the loading rollers, as shown in **Figure 6**.

These modes of collapse are confirmed by a number of investigations [6,8] The final failure for all the static tests occurred in the top skin and the core by a local indentation in the vicinity of the loading points, as illustrated in **Figure 6**. The localization of the damage in all cases was in the region close to the support, between the support and the adjacent load application.

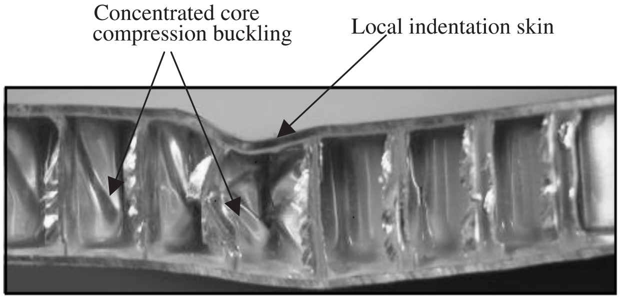


Figure 6: Failure mode showing local indentation skin and cell buckling
Slika 6: Način poškodbe z lokalnim vdorom in izločanjem aluminijastih celic

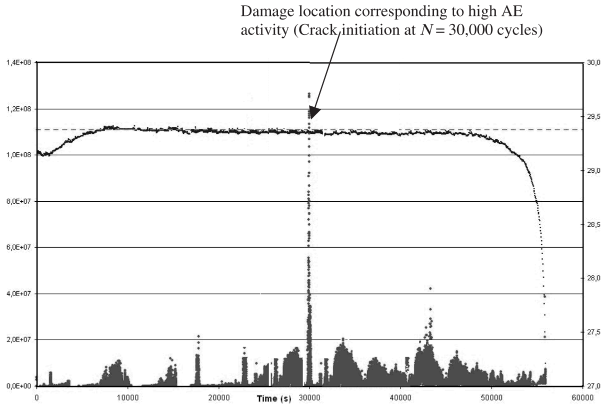
3.2 Fatigue tests

To investigate the effect of the defect (hole) on the fatigue life, flexural tests were performed in the cell direction L for an aluminium-aluminium sandwich panel with 82 kg/m^3.

Both curves (**Figures 7 and 8**) show the AE activity (Energy) vs. time and the minimal displacement vs. time. AE makes it possible to locate the crack initiation. Indeed, when the crack begins to grow there is a peak in the energy consumed. The displacement vs. time dependence shows that the crack initiation occurred at the same time.

The Wöhler curves were plotted with all the results of these tests and compared to the results for the same panels without a defect (**Figure 9**).

The results show that the fatigue life is the highest for the panels without a defect for the same applied load. Indeed, for an applied load of 65 % of the ultimate static load the number of cycles to failure is about of 5.10^5 cycles (**Figure 9**) for the panel with a defect, while for the panels without a defect it is greater than 10^6 cycles. The final fractures for the panels with and without a defect are shown in **Figure 10** and **Figure 11**, respectively. The crack started at the hole and grew in terms of its width (**Figure 10**).


Damage location corresponding to high AE activity (Crack initiation at $N = 30{,}000$ cycles)

Figgure 7: Results for sample 1. AE activity (Energy) and the minimal displacement vs. time (80 % ultimate load)

Slika7: Primer AE aktivnosti za preizkušanec 1 in minimalen upogib v odvisnosti od časa (80 % končne obremenitve)

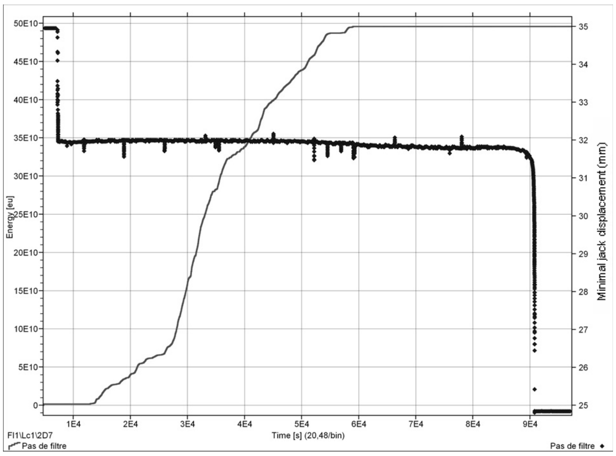


Figure 8: Results for sample 2. AE activity (Energy) and the minimal displacement vs. time (70 % ultimate load)

Slika8: Rezultati AE aktivnosti za preizkušanec 2 in minimalni upogib v odvisnosti od časa (70 % končne obremenitve)

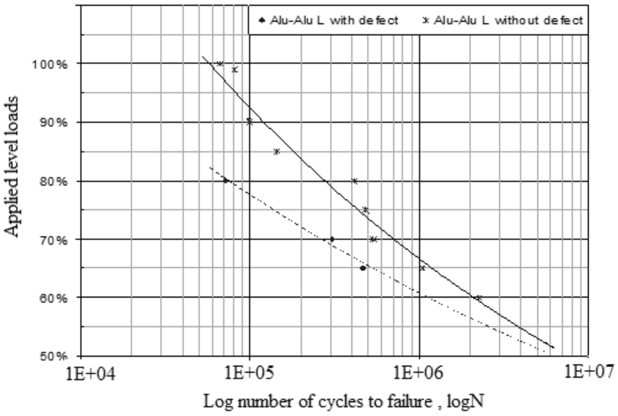


Figure 9: Wöhler Curves Aluminium-Aluminium

Slika 9: Wöhlerjeve krivulje aluminij-aluminij

4 CONCLUSION

Defect effects in static and fatigue studies of honeycomb core sandwich panels were investigated and the following observations were made.

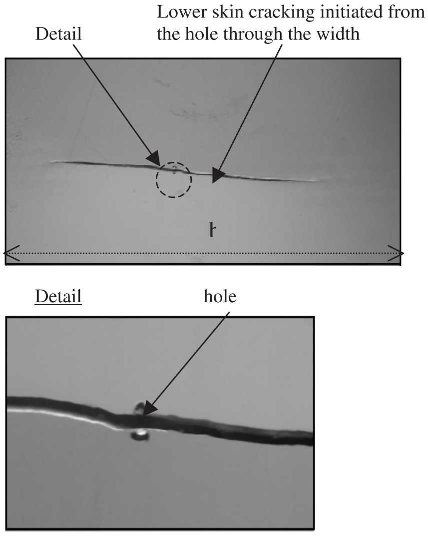


Figure 10: Fatigue-failure mode showing cracking skin through the defect

Slika 10: Utrujenostna poškodba, ki prikazuje razpoke skozi kožo

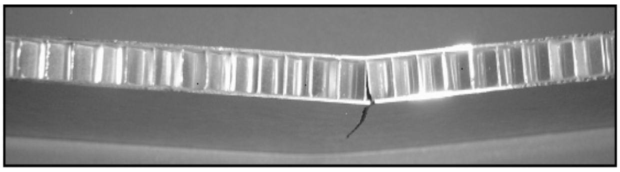


Figure 11: Fatigue-failure mode of the panel without a defect

Slika 11: Način preloma panela brez napake

No defect effect was observed in the case of the static study, in contrast to the case of the fatigue behaviour of the sandwich honeycomb panels. In the fatigue study, the fatigue life of the defect panels decreased rapidly when the applied load increased, compared to the panels without a defect. The results of the acoustic emission show the crack initiation and propagation and can be used as a reliable survey method for the damage mechanisms. The analysis of the acoustic signals confirmed that the majority of the damage growth occurs at peak-load levels and demonstrated the significant effect of the loading level on the progress of the damage.

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