THREE STAGES OF COMPOSITE SPECIMEN DESTRUCTION IN STATIC FAILURE

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The paper presents the results of standard specimen fracture made of anisotropic carbon fiber plastic with an epoxy matrix. Static stepwise loading of the specimen was carried out on an Instron 8801 testing machine to determine the characteristics of ductile fracture G_{IC} in the first mode in accordance with ASTM D5528.

During loading, the parameters of acoustic emission (AE) signals, such as AE impulse amplitudes and their energy were synchronously recorded. At the same time, the magnitude of the opening and the growth of the crack initiated by the artificial cut at the end of the specimen were recorded.

According to the analysis of the acoustic emission signals, three zones with different G_{IC} behaviour were identified: initial crack propagation, its stationary growth and accelerated fracture of the specimen. The zonal character of the change in the acoustic emission signals made it possible to determine the energy of the acoustic emission signals as diagnostic evidence for the onset of rapid destruction of the specimen.

The amplitude of the AE-signals in the zones, however, remained constant. Online monitoring of changes in the energy of acoustic emission signals will prevent the onset of rapid destruction of an object in places of its deformations. The paper does not aim at defining G_{IC} as usual. It presents the investigation of the fracture stages for a composite material using an acoustic emission method.

Keywords: *Acoustic emission data analysis, carbon fiber, composite specimen destruction.*

1. INTRODUCTION

The paper deals with the determination of opening Mode I interlaminar fracture toughness, G_{Ic} , for continuous fiber-reinforced composite materials using the double cantilever beam (DCB) specimen. During testing, an acoustic emission (AE)

method was applied to obtain experimental data. G_{Ic} calculation was performed in compliance with ASTM D5528 [1] using a method of Modified Beam Theory (MBT) (Fig. 1).

Fig. 1. Scheme of determination of G_{Ic} according to ASTM D5528.

where P – load, N; δ – crack opening, mm; b – specimen width, mm; a – crack length, mm; AE – acoustic emission gauge.

2. EXPERIMENTAL

Specimens were made of carbon fiber zero-degree orientation (see Fig. 2). On the both sides, metallic hinges have been glued to transfer load during loading. The dimensions of specimens are 200 mm x 25 mm x 3 mm. Before testing, in each specimen cleavage about 50 mm was made as crack initiator with utility knife. The Instron 8801 machine was used for specimen stepwise loading (loading-unloading). The Instron 8801 100 kN is a compact servo hydraulic fatigue testing system that meets the challenging demands of various static and dynamic testing requirements. 8801 systems provide complete testing solutions to satisfy the needs of advanced materials and component testing, and are ideally suited for fatigue testing and fracture mechanics [2]. For measurement crack length and

crack opening, digital caliper was used [3]. During testing, Vallen system AMSY-6 digital multi-channel acoustic emission (AE) acquisition system was used. Vallen AMSY-6 is a fully digital multi-channel AE measurement system. A measurement channel consists of an AE sensor, preamplifier and one channel of an ASIP-2 (dual channel acoustic signal processor). Each channel combines an analogue measurement section and a digital signal processing unit. AE features, such as time of the first threshold crossing (arrival time), rise time, duration, peak amplitude, energy and counts, are extracted by the ASIP-2 [4]. According to the procedure, the calibration was performed using a standardized source of Hsu-Nielsen (Hsu-Nielsen source). In this case, the threshold value was 30.1 dB [5].

The AMSY-6 provides four types of measurement data:

- Hit data: data that are generated when the AE signal exceeds the threshold;
- Status data: data that are generated in regular time intervals;
- Parametric data: data of external para-

metric sensors which are measured at regular time intervals. Parametric data are stored with every hit and at user-specified time intervals;

- Waveform data: sampled AE sensor signal.

Fig. 2. General view of specimen.

3. RESULTS AND DISCUSSION

The results of loading and measurements are averaged values over three speci-

mens (see Table 1).

Table 1. The Results of Loading and Measurements

Average load, N	Average crack opening, mm	Average crack length, mm	Average G_{IC}	Average AE Energy, J	Average amplitude, A
0	0.00	50.91	0.00	27643	69.3
48	5.83	52.07	0.27	829802	83.6
69	7.57	54.04	0.50	1835112	94.8
77	8.62	55.58	0.61	8001274	95.9
68	10.18	58.93	0.60	32349678	100.0
65	11.34	60.51	0.62	17617166	100.0
59	12.59	64.88	0.58	2101359	96.0
51	13.92	66.19	0.55	11062139	100.0
51	15.42	67.96	0.58	8762451	99.8
45	17.47	70.97	0.56	18522012	100.0
39	19.57	76.21	0.51	6130811	86.3
36	20.88	78.73	0.48	802792	92.2
31	23.93	82.68	0.46	4653842	99.1
29	27.03	87.22	0.45	6168770	100.0
26	30.46	92.14	0.44	11803327	100.0
25	32.98	95.21	0.44	4050307	86.4
12	37.77	102.50	0.33	635252	81.7
9	42.30	103.60	0.19	32199243	100.0

Energy is given in energy units (eu) and the software takes the selected gain into account, when calculating and displaying energy. Energy is calculated by squaring the digitized AE signal and integrating the results during the hit. 1 eu corresponds to $10^{-14} \text{V}^2 \text{sec}$ at the sensor output [6]. Energy is processed in either the so-called true

energy mode or a signal strength mode. In both modes, energy is given in energy units and the software takes the selected gain into account, when calculating and displaying energy. Energy is stored in a logarithm format with a resolution of 0.1 %.

Figure 3 shows the change in G_{Ic} with loads.

Fig. 3. The change in the fracture toughness in Mode I in the load.

A characteristic change in fracture toughness is observed during an increase in the load [7]. Due to a non-monotonic increase in the fracture toughness value, it is very difficult to determine the moment of termination of loading for its calculation.

Figure 4 demonstrates a comparison of the change in crack opening and crack length. An increase in crack opening and crack length depends on the loading. After maximal load cracks continue increasing, but the loads decrease.

Fig. 4. The change in crack opening and crack length evolution during loading.

As the probable moment of specimen destruction cannot be predicted exactly and crack opening is difficult to measure on a real object, there is a problem related to the operation of instrumental control over the beginning of accelerated destruction of the specimen [8].

Let us consider the changes in the parameters of acoustic emission signals under loading of the specimens. The use of the acoustic emission method for full-scale bench tests of aircraft structures and/or their components shows that this method

is the most effective and convenient to use for monitoring the technical state of the controlled object [9]–[13]. This integrated method allows monitoring a rather extensive area free of NDT Operator in the on-line regime [14]. When diagnostic signs of incipient fracture appear, it becomes possible for the Operator to periodically use other methods of instrumental control of a suspicious area, but already in specific places of destruction [15], [16].

Table 2 shows loading stages for each measurement channel.

Table 2. Three Stages of Composite Specimen Destruction

Recording parameter	Initial zone, P	Increasing zone, P	Destruction zone, P
G_{1c}	0–48 N	48–12 N	12–9 N
Crack opening, mm			
Crack length, mm			
AE energy, eu			
AE amplitude, A			

Figure 5 shows changes in the AE energy and amplitude, and Fig. 6 demon-

strates changes in the AE energy and G_{1c} .

Fig. 5. Changes in AE energy and amplitude versus the load.

Fig. 6. Changes in AE energy depending on the G_{Ic} .

Figures 5 and 6 clearly show three zones of successive destruction of the composite material of the specimens. Thus, it is possible to objectively record the moment of the onset of accelerated destruction of

the specimen. The most pronounced criterion here is the change in the energy of acoustic emission signals, while the maximum amplitude of the AE signals does not so characteristically record this moment.

4. CONCLUSIONS

The investigation of the fracture toughness of Mode 1 allows observing the moment of decreased loading. However, this moment is determined subjectively, and then impossibility of withstanding the load or its fall occurs. The research has shown that the nature of the sequential fracture of the composite material of standard specimen with a longitudinal cut is characterised by three zones: initial (from the moment the crack starts to move in the cut), stationary, and accelerated.

On-line acoustic emission monitoring

of specimen fracture made it possible to objectively observe these zones and showed that the main diagnostic criterion was the energy of the acoustic emission signal. Thus, it will be possible to use this method in real designs subjected to deformations. The use of the acoustic emission method allows predicting the start and accelerated destruction of the weak elements. The composite products and structures during their deformations give objective information to Health and Usage Monitoring Systems.

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