Faculty of Engineering
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ACOUSTIC EMISSION

workshop Report

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Introduction

The term acoustic emission "AE" describes a transient elastic wave produced by a quick release of energy from a local source inside of a material under stress. The origins of acoustic emission are the mechanisms of fracture or deformation behaviors inside materials, such as crack initiation and growth, microstructural separation, and movement between material phases. The strain energy generated from freshly formed fracture surfaces often relates to the energy of sound emission. A correctly configured AE sensor array can detect and identify AE waves, which spread according to the material's sound velocity [1].

Pencil-lead Breakage Test

The Hsu-Nielsen source, commonly known as pencil-lead breakage (PLB), is a long-established standard for a repeatable artificial AE source, based on the original studies of Hsu and Nielsen. The lead of a mechanical pencil is applied forcefully to the structure being studied until the lead breaks. The structure’s surface deforms when pressure is applied to it with lead. The accumulated stress is suddenly released at the time of lead fracture, causing a tiny displacement of the surface and an acoustic wave that travels within the structure. It became the most used form of test source in AE testing because it is simple to handle in both lab and field-testing settings [2].

Test Setup

To track the progression of damage, AE testing entails storing and analyzing AE signals. This is often done by loading the structure and directly linking piezoelectric transducers to the surface of the structure being tested. The piezoelectric sensors' output is amplified by a low-noise preamplifier (during stimulation), filtered to remove any unwanted noise, and then further processed by appropriate electronics as seen in Figure 1 [3].

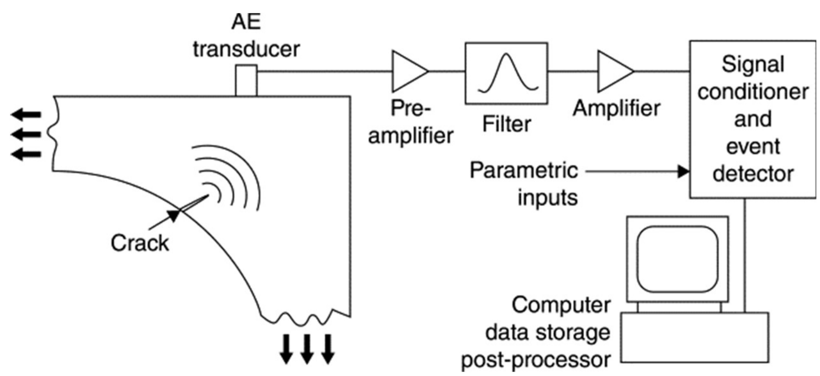

Figure 1 Acoustic emission test setup

AE Signal Parameters

Hits are triggered and the time of arrival is recorded when the voltage measured by sensors crosses the threshold. An extra peak definition time (PDT) is collected when the signal amplitude reaches its highest and begins to fall to determine if the prior signal amplitude has been exceeded. If so, the measurement is carried out; if not, the maximum amplitude is the prior value. The latest threshold crossing is noted while the signal continues. The final recorded time marks the end of the signal if there are no more surpassing during the hit definition time (HDT). The system continues to register the waveform until a specific period (maximum duration), at which point it automatically designates the end of the signal if the signal never falls below the threshold within the HDT. The HDT (hit lockout time) is the time waited until the signal expires following either the maximum duration or HDT has been achieved. Then, the system resets and is prepared to receive the subsequent signal [4].

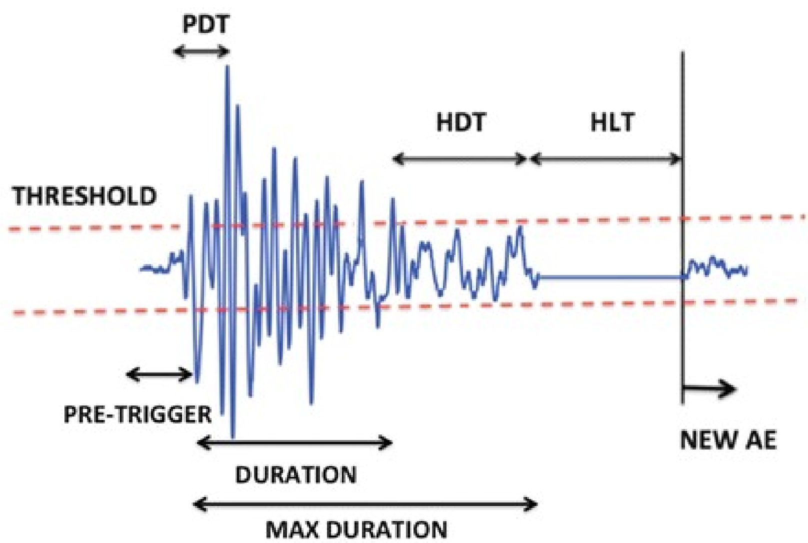

Figure 2 Acoustic emission signal parameters

Objectives

This workshop aims to use the PLB test to understand AE in composite materials and evaluate the resulting waves through AE software and simple coding statements.

The workshop focused on two experiments: using AE software and eliminating noise obtained through a simple PLB test at different distances from the piezoelectric sensor on a composite structure, and calculating AE velocity through another PLB test using two piezoelectric sensors at a different position to the artificial source by using the difference in the arrival time of the signal between the two sensors.

Equipment

- Piezoelectric Sensor
- 1283 USB AE Node
- USB Cable
- PC or Laptop with "AEwin for USB" program installed
- Mechanical pencil and lead

Figure 3 Equipment required for the experiments

Procedures

Experiment 1

1. Fix the piezoelectric sensor on the composite body.
2. Connect the sensor with the node and the node with the PC or laptop.
3. On the tested body, add seven marks with linear spacing; each mark is 5 cm away from the consecutive mark as seen in Figure 4.

4. Open the “AEwin for USB” program and modify the settings to fit your experiment parameters.
5. As readings get recorded, break the lead at the marked points from the closest to the sensor to the furthest.
6. Abort recording and export the reading as CSV files.
7. Plot the readings and remove noise signals.
8. From the selected plots, find the maximum amplitude for each signal.
9. Plot and find the relation between the maximum amplitude and the distance from the sensor.

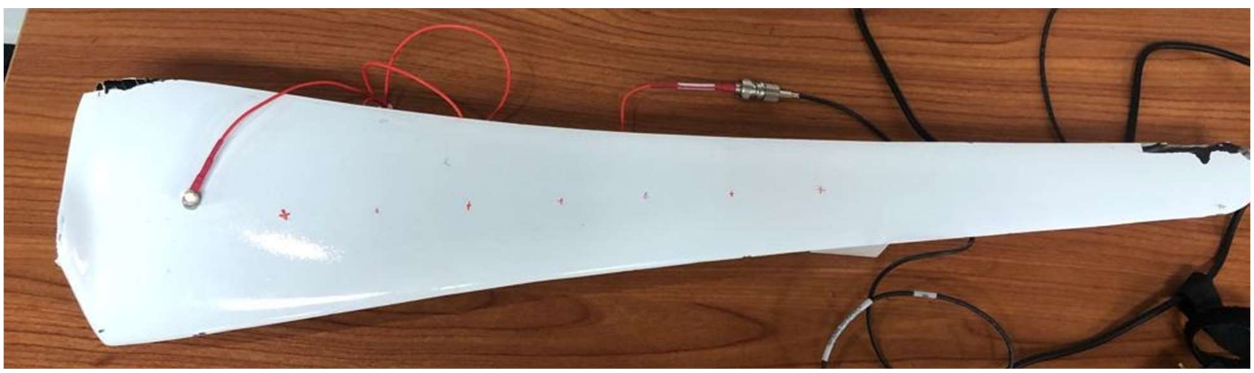

Figure 4 Experiment 1 setup

Experiment 2

1. Fix two piezoelectric sensors on the composite body at a known distance – of 25 cm.
2. Connect the sensors with the node and the node with the PC or laptop.
3. On the tested body, mark a point close to one sensor and far from the other as seen in Figure 5.
4. Open the “AEwin for USB” program and modify the settings to fit your experiment parameters.

5. As readings get recorded, break the lead at the marked point five times.
6. Abort recording and export the reading as CSV files.
7. Plot the readings and find the time of arrival for each plot.
8. Calculate the difference in time of arrival between the two sensors for each trial.
9. Use the time difference to calculate the velocity for each trial.
10. Find the average velocity and compare the results with velocities from the literature.

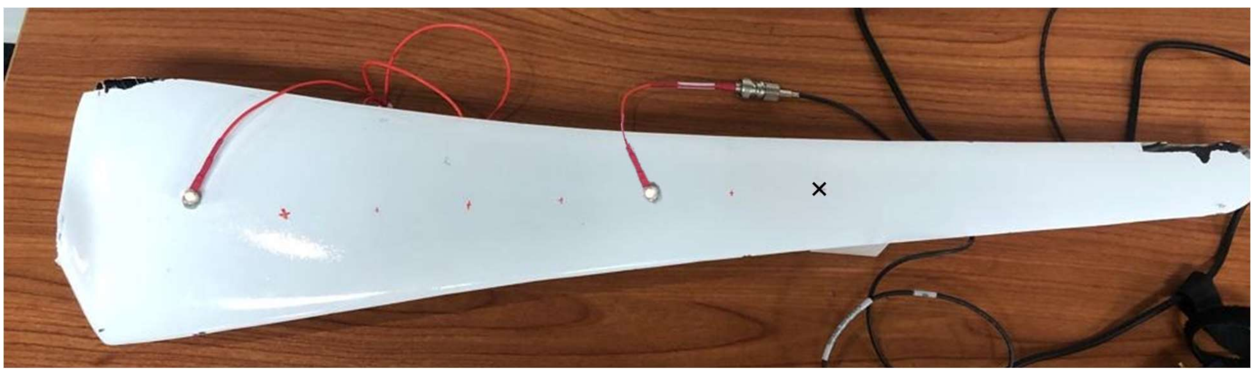

Figure 5 Experiment 2 setup

Data and Results

Experiment 1

The seven trials of the experiment at different points lead to the generation of ten signals, meaning that three signals are noise and should be removed for accurate results. After plotting all the signals using MATLAB code (see Figure 11), the following graph is found.

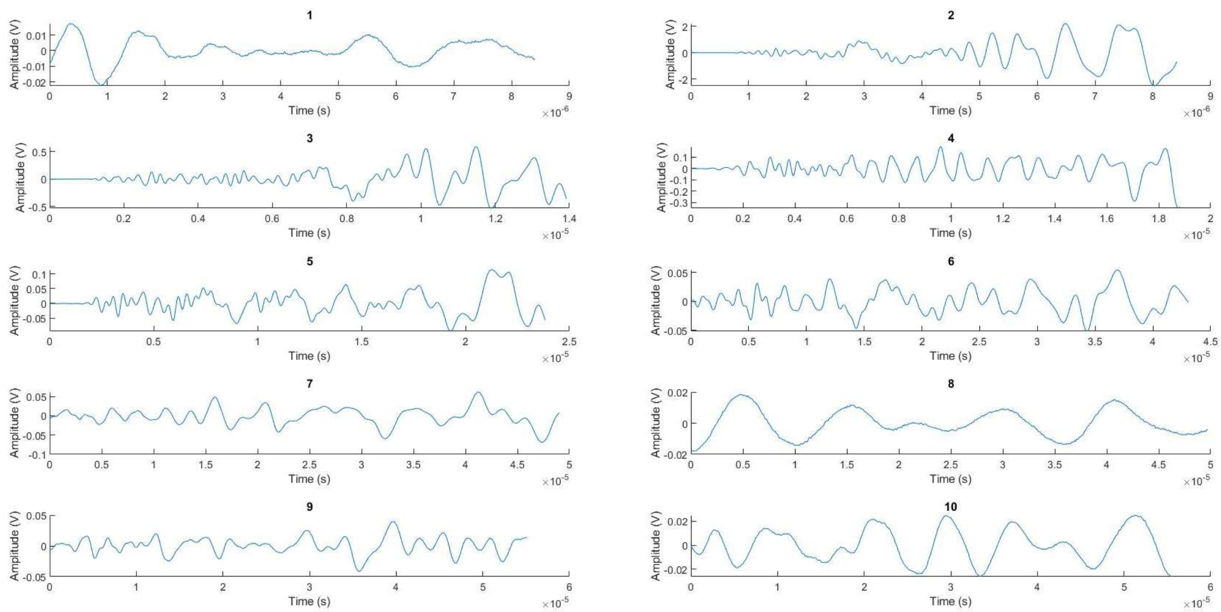

Figure 6 signals of experiment 1

By evaluating the plotted curves, it was deduced that graphs 1, 8, and 10 should be eliminated. Then, through the MATLAB code, the maximum amplitude for each signal is collected and plotted against the distance measured from the sensor as seen in the following graph.

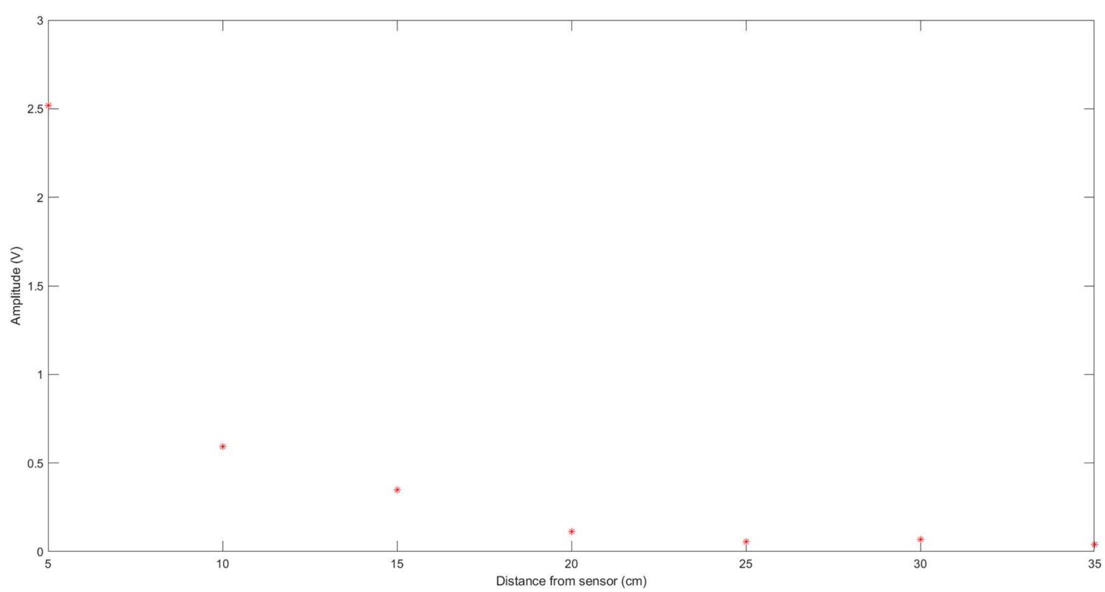

Figure 7 Maximum amplitude against distance from the sensor

Experiment 2

The five trials of the experiment led to the generation of ten signals; each trial had two reading from the two sensors. After plotting all the signals using MATLAB code (see Figure 12), the following graph is found: the left graphs represent the signals captured by sensor 1 and the right graphs represent the signals captured by sensor 2. To find the time of arrival for each signal, the Akaike Information Criterion (AIC) was calculated for each point in the obtained data (see Figure 13) to determine its minimum value which is equivalent to the arrival time of the signal.

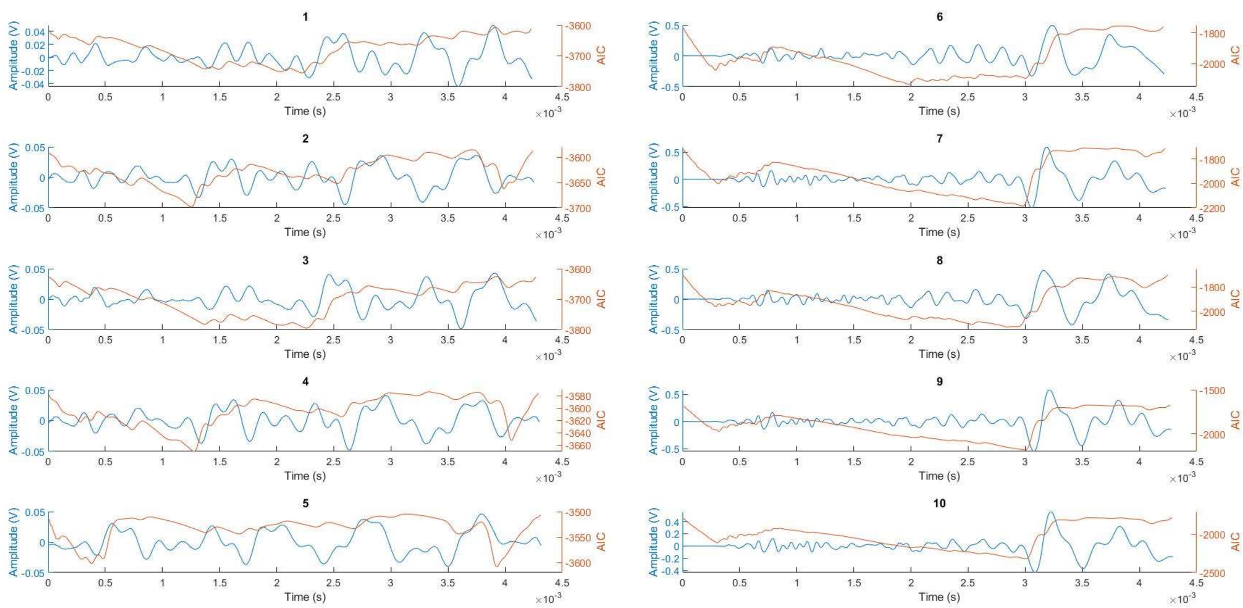

Figure 8 Signals of experiment 2

By observing the plots, the AIC value has its lowest values at delayed times for sensor 2 while for sensor 1, it is challenging to determine the time of arrival whether using AIC or through the signal plots. Therefore, the values of the AIC were evaluated for the first 200 points only to find the minimum value from these points and check if for each sensor the time of arrival is relatively close to the values of the trials by measuring the variance for the five trials. If the variance is extreme, the time of arrival is set to 0 (see Figure 12). The value of the mean velocity calculated from the obtained data is 1075.5 m/s.

Discussion

Experiment 1

The plotted points in Figure 7 show a decaying exponential trend that can be further fit into an exponential curve using a fitting function in MATLAB (see Figure 11). The best fit function that can describe this exponential decay is

$$A(x) = 8.981e^{-0.2555x}$$

And is presented in Figure 9. The exponential decrease of the amplitude in volt with the increase of distance between the artificial source and the sensor is due to signal attenuation.

Experiment 2

The calculated average velocity can be compared to previous work to determine its reliability. Lopresto V. et al. [5] studied the effect of changing carbon fiber orientation and layering on the extensional velocity of the acoustic wave through the same test procedure done in this workshop. Their findings can be summarized as the velocity in carbon fiber should range between approximately 2000-6000 m/s depending on the orientation of the fiber as shown in Figure 10. The divergence in the velocity can be due to inaccurate calculation of the time of arrival for signals of sensor 1.

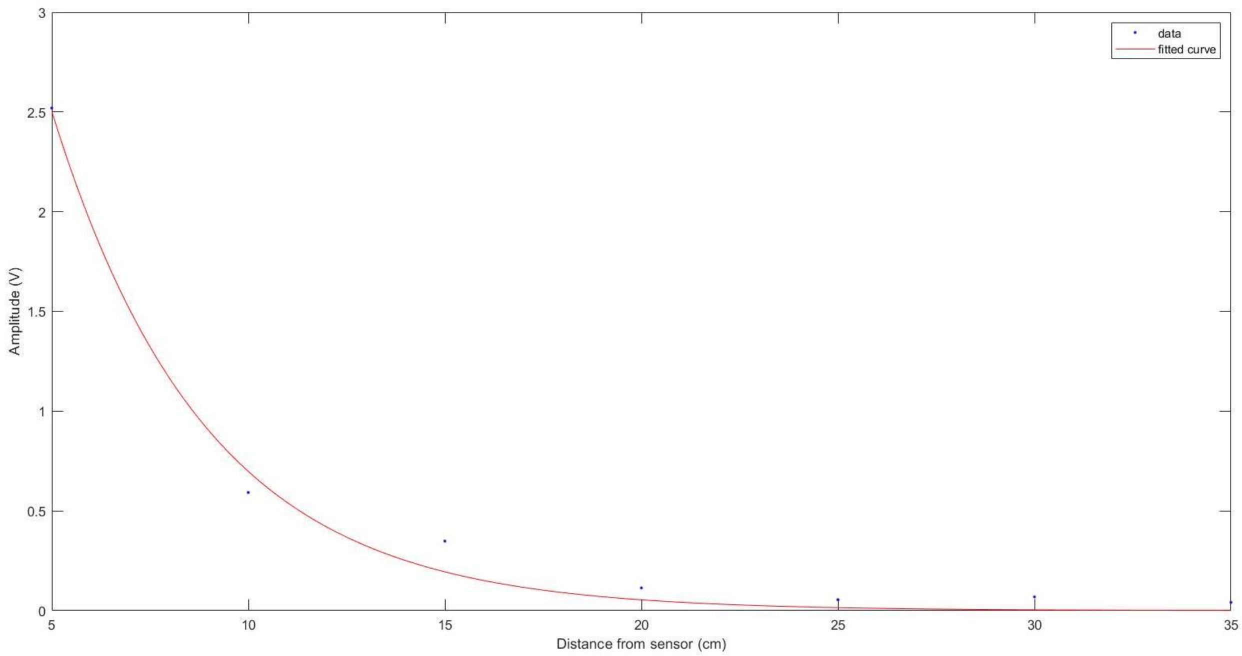

Figure 9 Best fit curve for experiment 1 data

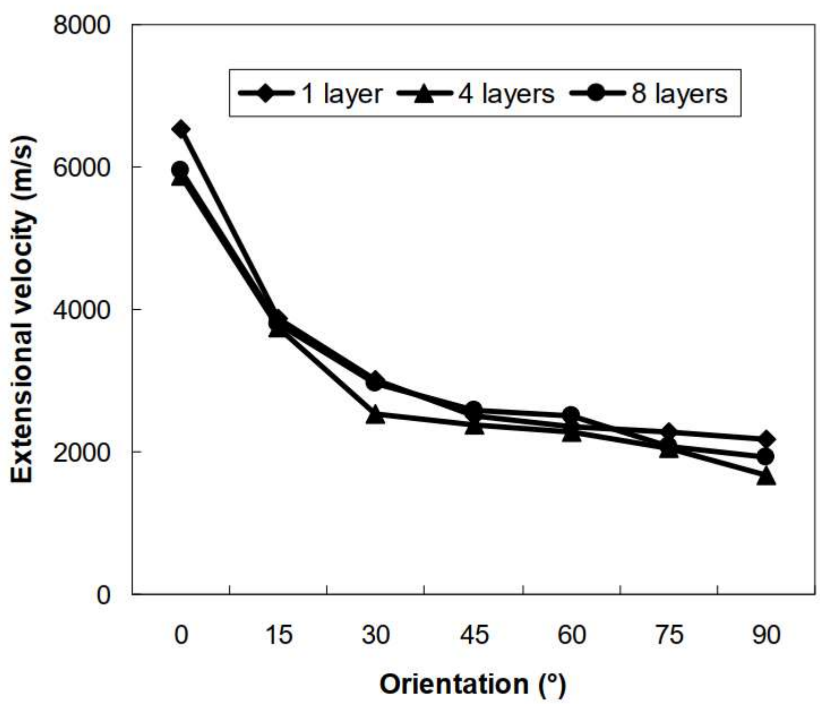

Figure 10 Extensional velocity against carbon fiber orientation

Conclusion

Acoustic emission is considered a turning point when it comes to non-destructive testing and monitoring of structures under their working conditions. This method does not require heavy equipment and - in comparison to other methods – is easy to use and interpret data to determine some failure mode characteristics such as the location of the initial crack or failure source.

In the workshop, we studied the attenuation characteristic of the acoustic wave in a composite structure produced from an artificial source which showed an exponential pattern by quantifying this phenomenon using the maximum amplitude (in volt) of the acoustic wave at the tested distance from the source.

In addition, we studied the mean velocity of the acoustic wave induced by an artificial source in the composite material by measuring the difference in the time of arrival using two sensors at a known distance. Further, we can determine the location of another artificial source using the measured mean velocity and the arrival time obtained from the experiment.

On the contrary, the velocity measured in the second experiment was not that accurate which can cause a further error in determining the location of another external source. Therefore, other methods have been developed to solve this issue and determine the location without the need to calculate the average velocity of the acoustic wave. Such methods can be introduced in later workshops.

References

[1] J.Q. Huang, Non-destructive evaluation (NDE) of composites: Acoustic emission (AE), Non-Destructive Eval. Polym. Matrix Compos. Tech. Appl. (2013) 12–32. https://doi.org/10.1533/9780857093554.1.12.

[2] M.G.R. Sause, Investigation of Pencil-Lead Breaks as Acoustic Emission Sources, J. Acoust. Emiss. 29 (2011) 184–196.

[3] Y. Dong, F. Ansari, 7 - Non-destructive testing and evaluation (NDT/NDE) of civil structures rehabilitated using fiber reinforced polymer (FRP) composites, in: V.M. Karbhari, L.S.B.T.-S.L.E. and E. of C.E.S. Lee (Eds.), Woodhead Publ. Ser. Civ. Struct. Eng., Woodhead Publishing, 2011: pp. 193–222. https://doi.org/https://doi.org/10.1533/9780857090928.2.193.

[4] Z. Moradian, B.Q. Li, Hit-Based Acoustic Emission Monitoring of Rock Fractures: Challenges and Solutions BT - Advances in Acoustic Emission Technology, in: G. Shen, Z. Wu, J. Zhang (Eds.), Springer International Publishing, Cham, 2017: pp. 357–370.

[5] V. Lopresto, C. Leone, G. Caprino, I. De Iorio, Analysis of acoustic emission signals produced by different carbon fiber reinforced plastic laminates, ICCM Int. Conf. Compos. Mater. (2009).

Appendix

```
File_Names=uigetfile('*.csv', 'Select Multiple Files', 'MultiSelect', 'on' );
N_Graphs=length(File_Names);
Maximum_Points=zeros(1,N_Graphs);
N_Points=input("Add number of points: ");
Distance_Points=input("Add distance between the points in cm: ");
t = tiledlayout(ceil(N_Graphs/2),2);
Time=zeros(1,N_Graphs);
for n=1:N_Graphs
CSV_File_Name=File_Names{n};
All_Data=readmatrix(CSV_File_Name);
All_Data(isnan(All_Data))=0;
Plot_Data=All_Data(12:end,1)+ All_Data(12:end,2);
Time=linspace(0,All_Data(9,4)*10^-6,length(Plot_Data));
nexttile
hold on
title(n);
xlabel('Time (s)')
ylabel('Amplitude (V)')
plot(Time,Plot_Data)
hold off
Maximum_Points(1,n)=max(abs(Plot_Data));
end
Rejected_Plots=input("Enter the numbers of plots you want to delete: ");
Maximum_Points=Maximum_Points(setdiff(1:n,Rejected_Plots));
Length_of_Specimen=Distance_Points.*N_Points;
figure
Distance_Array=Distance_Points:Distance_Points:Length_of_Specimen;
plot(Distance_Array, Maximum_Points,'bo');
hold on
xlabel('Distance from sensor (cm)')
ylabel('Amplitude (V)')
hold off
figure
Fitted_Data=fit(Distance_Array',Maximum_Points','exp1');
plot(Fitted_Data,Distance_Array,Maximum_Points)
hold on
xlabel('Distance from sensor (cm)')
ylabel('Amplitude (V)')
hold off
```

Figure 11 Experiment 1 code

```
File_Names=uigetfile('*.csv', 'Select Multiple Files', 'MultiSelect', 'on' );
N_Graphs=length(File_Names);
TOA=zeros(1,N_Graphs);
TOA_Index=zeros(1,N_Graphs);
N_Sensors=2;
Distance=input('Enter distance between sensors in m: ');
t = tiledlayout(ceil(N_Graphs/2),2);
Rows=[1:2:N_Graphs,2:2:N_Graphs];
Time=zeros(1,N_Graphs);
for n=1:N_Graphs
CSV_File_Name=File_Names{n};
All_Data=readmatrix(CSV_File_Name);
All_Data(isnan(All_Data))=0;
Plot_Data=All_Data(12:end,1)+ All_Data(12:end,2);
AIC=AIC_Calculator(Plot_Data);
Time=linspace(0,All_Data(9,4)*10^-6,length(Plot_Data));
nexttile(Rows(n));
hold on
title(n);
yyaxis left
plot(Time,Plot_Data)
yyaxis right
plot(Time,AIC)
hold off
AIC(AIC==-inf)=0;
[~,TOA_Index(1,n)]=min(AIC(1,1:200));
TOA(n)=Time(TOA_Index(n));
end
T_Sensor1=TOA(1:N_Graphs/2);
T_Sensor2=TOA((N_Graphs/2)+1:end);
if var(T_Sensor1)>10^-9
   T_sensor1=zeros(1,N_Graphs/2);
end
if var(T_Sensor2)>10^-9
   T_sensor2=zeros(1,N_Graphs/2);
end
Velocity=Distance./abs(T_Sensor2-T_Sensor1);
Velocity_Av=mean(Velocity)
```

Figure 12 Experiment 2 code

```
function AIC = AIC_Calculator(Data)
N_sample=length(Data);
AIC = zeros(1,N_sample);
for n=1:N_sample
    AIC(n)=n.*log10(var(Data(1:n)))+(N_sample-n-1).*log10(var(Data(n+1:N_sample)));
end
```

Figure 13 AIC code function