International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.6 (2016), pp.227-240
http://dx.doi.org/10.14257/ijmue.2016.11.6.20

Propagation Characteristics of Acoustic Emission in Plate Structure with Various Materials and Multilayer Medium

Kuanfang He, Zhi Tan, Yong Cheng and Chao Wang

Hunan Provincial Key Laboratory of Health Maintenance for Mechanical Equipment, Hunan University of Science and Technology, Xiangtan, China, 411201
Email: hkf791113@163.com

Abstract

Acoustic emission signal is a kind of elastic wave which is caused by the release of internal energy of materials when the structure changes. The propagation characteristics of acoustic emission is important to the testing technology of a structure by acoustic emission signal. The finite element method is introduced to analyze elastic wave propagation in plate structure in the article, which mainly contains the discretization techniques of the area and time domain. The structure plate with different materials ,style and coating metal are selected in finite element simulation, the displacement contours and wave curve resulted from simulation are used to analyze the interface reflection, refraction and diffraction process as well as the wave type conversion in different medium of the elastic wave propagation . The mechanical pencil lead fracture experiment is done to verify the transient simulation of elastic wave propagation in plate structure.

Keywords: *Plate structure; acoustic emission; elastic wave; propagation characteristics; Finite element method*

1 Introduction

The acoustic emission signal is a kind of elastic wave which is formed by the release of the internal energy of materials when the structure changes [1-2]. The acoustic emission signal contains rich information of the structure. In order to interpret the detected acoustic emission signals in terms of their relevance to material failure, it is required to have concise knowledge of propagation of acoustic emission signal in structure. These acoustic waves propagate within the solid can be detected at the surface by suitable sensor systems [3-4]. This method is known as acoustic emission analysis and its significance to structural health monitoring as well as its ability to improve material testing procedures has already been proved [5]. The experimental approaches [6-10] recently have focused on using guided wave propagation to interpret AE signals to better discriminate and eliminate extraneous noise signals, and to enhanced identification of AE sources.

The visualization of acoustic emission wave propagation is effective for understanding the complicated wave phenomenon in anisotropic material. Z. You *et al*. [11] developed a two dimensional finite element code and showed wave propagation in an orthorhombic medium, and Z. You *et al*. [12] discussed amplitude loss in anisotropic material by developing an axisymmetric finite element code. K. M. A. Jaleel *et al*. [13] discussed a wave scattering by cracks in orthotropic graphite/epoxy composite material by using finite element method. Hamstad and Gary [14-15] applied finite element modeling to simulate acoustic emission sources based on body forces acting as a point source in a solid. Hora and Cervena investigated the difference between nodal sources, line sources and cylindrical sources to build more representative geometrically acoustic emission sources

ISSN: 1975-0080 IJMUE

[16]. At the same time, Sause, and Horn [17] proposed a finite element approach using an acoustic emission source model in the vicinity of the acoustic emission source. Wilcox [18] described wave propagation by numerical methods with a main focus in the improvement of the calculation routines. The theoretical description and numerical implementation of wave propagation is already well established. However, it is important to consider the effects of attenuation, dispersion and propagation in guiding media to capture the characteristics of the signal accurately. However, only a small amount of work has been performed recently to advance the understanding of the physical processes involved in the propagation characteristics of acoustic emission in the structure with various materials.

In this paper, we apply the finite element method to study the elastic wave propagation characteristics in plate structure with various materials .The displacement contours and wave curve are obtained from the simulation to analyze the interface reflection, refraction and diffraction process as well as the wave type conversion in different medium of the elastic wave propagation. The experimental work is based on a pencil broken test stage to validate the transient simulation of elastic wave propagation in plate structure with different materials and metal coating, and comparison is made between the experimental results and the results from the different types of acoustic emission source simulation.

2. Finite Element Numerical Method

2.1 Equations of Motion

Equation of motion for isotropic elastic solid neglecting body forces and viscous attenuation is expressed as

$$(\lambda+\mu)\nabla\left(\nabla.\vec{u}\right)+\mu\nabla^2\vec{u}=\rho\ddot{\vec{u}} \tag{1}$$

Where $\vec{u}$ is the displacement, p is the density of the solid and $\ddot{\vec{u}}$ is the particle acceleration.

The element matrix equation of motion is derived from equation (1) with the area discretization after conduct virtual displacement energy minimization method.

$$M\ddot{U}+KU=F \tag{2}$$

Where M is global mass matrix, and K is stiffness matrix, F is the force vector load vector, U is node displacement vector.

2.2. Acoustic Emission Wave Propagation in Plate Structure with Homogeneous Material

The transit displacement of a point in plate structure is the diffusion spread of the energy in the form of wave. The Figure 1, Figure 2 are the three dimensional elastic wave propagation process from fluctuations of displacement amplitude.

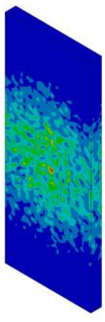


Figure 1. Wave Fluctuations of 3D-Plate

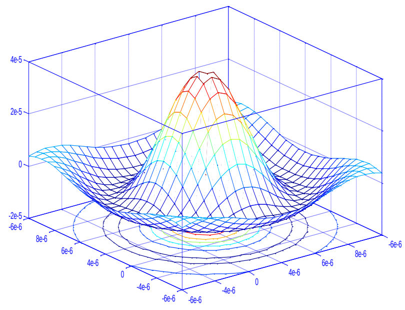


Figure 2. Central Symmetric 3D Elastic Wave

The plate material is GGr15 steel with specific parameters: density $\rho = 7810 kg/m^3$, Modulus of elasticity $E = 206GPa$, Poisson's ratio $nuxy = 0.3$, the vertical section length of the plate is 20 mm with the width of 8mm. The wave velocity in the steel materials GGr15 is $v = 5893m/s$. The forces were applied with a "cosine bell" ,time dependence $f(t)$ given by:

$$f(t) = \begin{cases} 0(t < 0) \\ (0.5 - 0.5\cos(\frac{\pi t}{\tau}))(0 < t < \tau) \\ 1(t > 0) \end{cases} \quad (3)$$

Where $\tau = 1.5\,\mu s$ is the source rise time. Computing space step is $0.06mm$, time step is $5ns$.The basic propagation of acoustic emission elastic wave can be seen from the fluctuations displacement contours. The chart wave color reflects the displacement value change as following: the red one is the maximum displacement value, the blue one is the minimum displacement value.

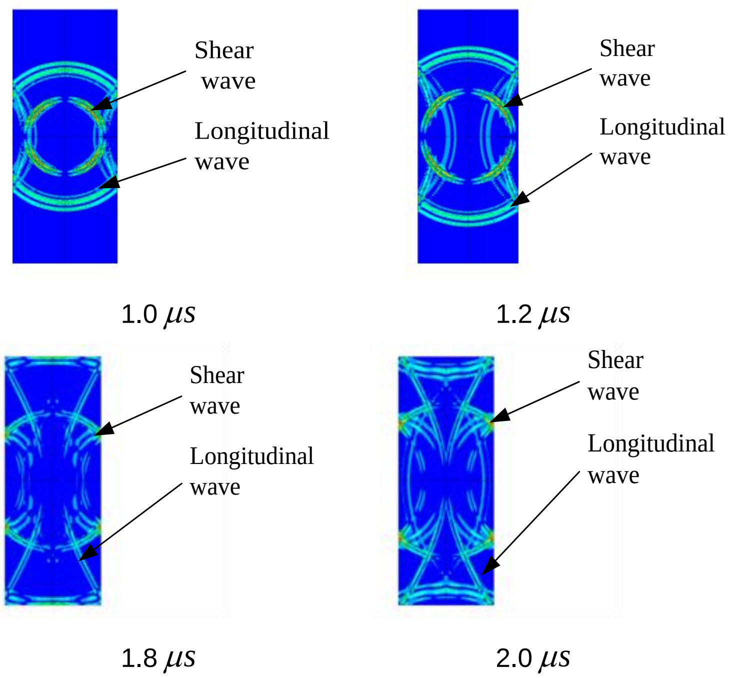
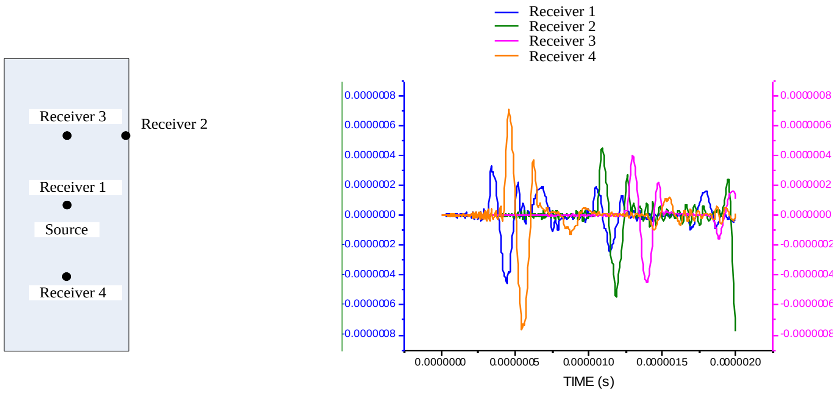


Figure 3. The Displacement Contour at Different Time

It can be seem from the displacement contour at 1.0 μs in Figure.3, acoustic emission elastic wave is divided into longitudinal wave and shear wave, the longitudinal wave and shear wave propagate from the wave source to the boundaries. The two kinds of wave velocity are obviously different, the longitudinal wave velocity is more fast than shear wave, but the amplitude of the shear wave is relative large. It also can be seem from the displacement contour at 1.2 μs −2.0 μs that elastic wave becomes more complicated after boundary reflection and wave coupling, making it difficult to distinguish between longitudinal and shear waves. The Figure.4 is the displacement waveform at different special position points (as show in Figure 4(a)) as time change, which reflects the displacement change by the effect of the wave source.



(a) The Source and the Receiver Positions (b) The Displacement Waveforms of the Receivers

Figure 4. The Displacement Waveform at Different Points

3. Acoustic Emission Wave Propagation in Plate Structure with Different Material

The plate structure with material of steel 45 and GCr15 are used to conduct comparative analysis of the acoustic emission propagation characteristics in the plate. The material specific parameters of the steel 45, the specific parameters density $\rho = 7.85 \times 10^{-6} kg / mm^3$, Elastic Modulus $E = 206GPa$, Poisson's ratio $\sigma = 0.28$. Figure.6 and Figure.7 are the displacement contours from the plane of steel GCr15 and steel 45 at the time 2.0 μs, Figure. 8 is the displacement waveform at the same special position points as time change, we can see the elastic wave propagation in the plane of steel 45 lagged behind the plate of steel GCr15.

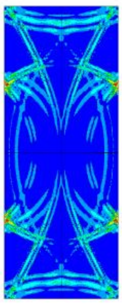


Figure 6. Displacement Contour of Gcr15 at Time 2.0 μs

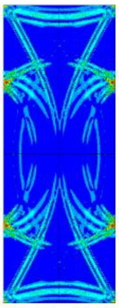


Figure 7. Displacement Contour of 45# at Time 2.0 μs

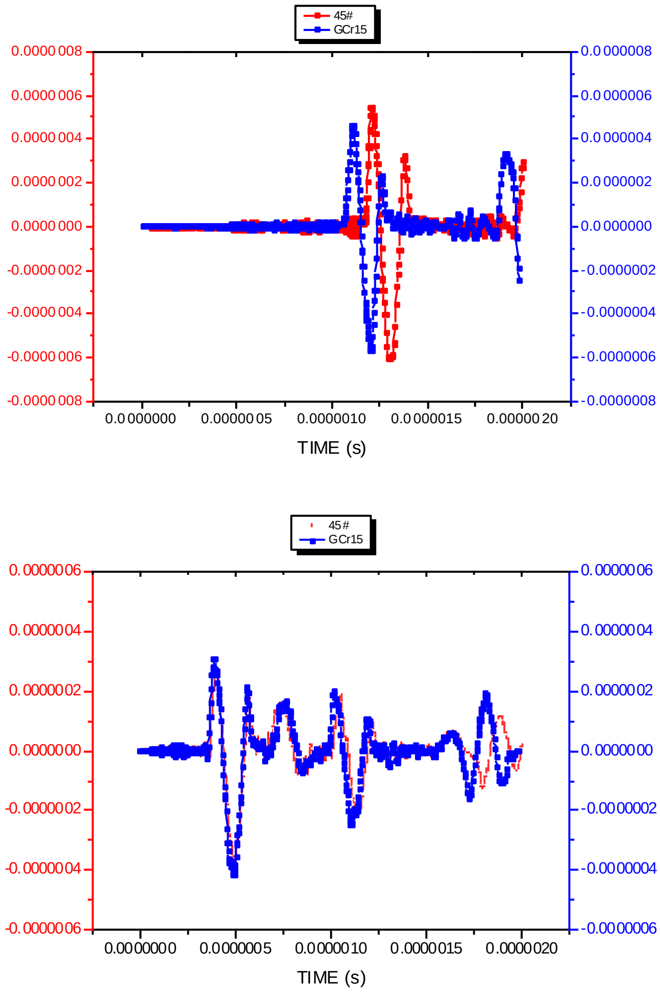
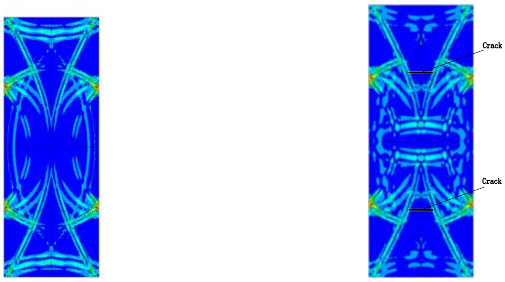


Figure 8. The Displacement Waveform with Different Material

The acoustic emission propagation in no crack and crack plate are shown in Figure 9 and Figure 10, we can see the elastic wave propagation in the plane with cracks becomes more complicated. Thanks to the interaction of the crack face, the elastic wave propagation occurs obvious emission and diffraction, especially the influence of diffraction lead to waveform presents the state of dispersion and it is obvious at time 2.0 μs. Figure 11 is the displacement waveform at the same position with cracks and no cracks plate.

(a) Displacement Contour in the No Crack Plate (b) Displacement Contour in the Crack Plate

Figure 9. Displacement Contour Comparison at Time 1.0 μs



(a) Displacement Contour in the No Crack Plate (B) Displacement Contour in the Crack Plate

Figure 10. Displacement Contour Comparison at Time 2.0 μs

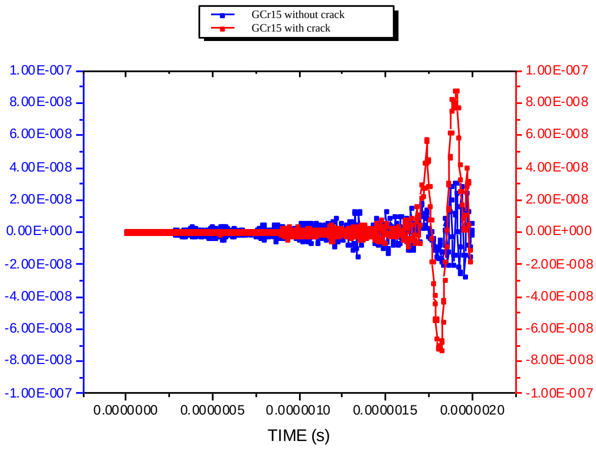


Figure 11. The Displacement Waveform at the Same Position with Cracks and No Cracks Plate

4. Acoustic Emission Propagation in Plate Structure with Multilayer Medium

In calculation process of the acoustic emission propagation in plate structure with multimedia layers, the conditions should be considered the following two keys. Firstly, the material parameters of the common node on the interface are set as the average of the two materials. Secondly, the continuity of the interface of two materials must be considered when mesh the model. The global mass matrix and the stiffness matrix can be obtained from the basis of the material parameters, the whole finite element equation is established, and the central difference method in time-domain is selected to solve specific problems . In general case, the space and time step length should be satisfied as the following conditions:

$$C_{\max} \quad \Delta t \le \Delta h / C_{\max} \tag{4}$$

Where Δt is the time step, Δh is space step, $C_{\max}$ is the material maximum longitudinal wave velocity.

In this paper, the plate with two layers of aluminum and steel is selected to be the object of elastic waves propagation characteristics simulation analysis. The thickness of the aluminum plate is 500 μm, the general thickness of steel 45 is 2 mm, a long section of 15 mm and width of 2.5 mm. In the finite element model, the material specific parameters of the aluminum layer are set as following: density $\rho = 2.7\times10^{-6} kg/mm^3$, Elastic Modulus $E = 70GPa$, Poisson's ratio $\sigma = 0.34$. The coated steel plate is steel 45, the specific parameters density $\rho = 7.85\times10^{-6} kg/mm^3$, Elastic Modulus $E = 206GPa$, Poisson's ratio $\sigma = 0.28$.

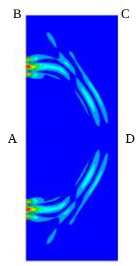


Figure 12. Displacement Contour of Aluminum at 0.8 μs

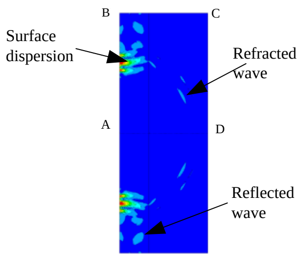


Figure 13. Displacement Contour of Multilayer Medium at 0.8 μs

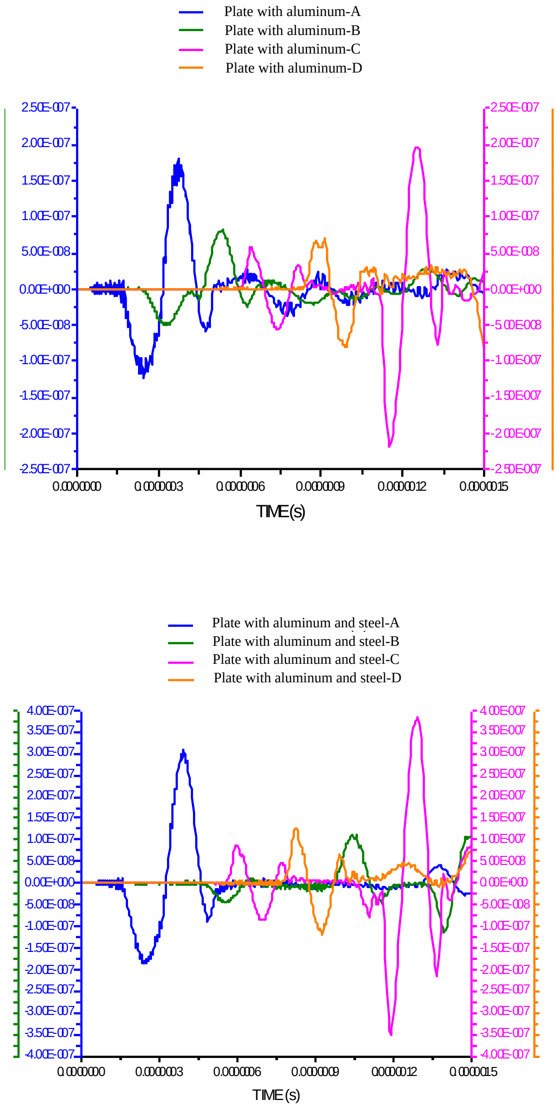


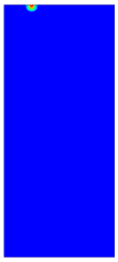
Figure 14. The Displacement Waveform of Aluminum and Plate with Aluminum and Steel Layers

Figure 12 is displacement contour in plate with aluminum at time 0.8 μs, and Figure. 13 is displacement contour in plate with aluminum and steel layers at time 0.8 μs.Acoustic emission elastic wave propagation in plate with aluminum is similar to plates with steel GCr15 or 45. However, it is different from the plate with aluminum and steel layers, the elastic wave propagation appears the phenomenon of refraction and diffraction due to the interference of the media interface, then only a small amount of wave can spread into the steel layer which can be seen from the Figure 13. Figure 14 is the displacement waveform in plate with aluminum and plate with aluminum and steel layers, we can see the displacement waveform in plate with aluminum and steel layers is not smooth due to the refraction and diffraction interference of the media interface, accompanying with instability and scattering phenomenon.

5. Comparison of the Simulation and Experimental Verification

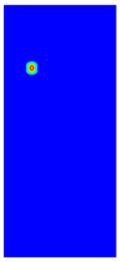
Four sound source nodes are selected to conduct simulation analysis and experimental verification. The positions of the sound source are shown in the Figure.15, accompanying with the displacement contour from four sources at time 0.1 μs .

(a) The First Sound Source



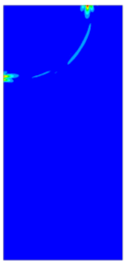
(b) The Second Sound Source

(c) The Third Sound Source



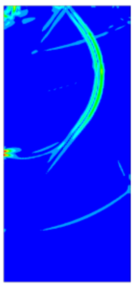
(d) The Fourth Sound Source

Figure 15. The Positions of the Sound Source with Displacement Contour at Time 0.1 μs

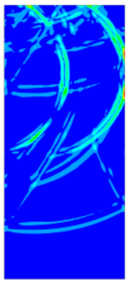


(a) The First Sound Source

(b) The Second Sound Source



(C) The Third Sound Source



(D) The Fourth Sound Source

Figure 16. Displacement Contour from Four Source at Time 2.0 μs

Figure 16 is the displacement contour from four sources at time 2.0 μs. Because of the phenomena of refraction, diffraction and dispersion affect by the boundary of plate, the propagation characteristics vary widely at different positions at the same time.

The mechanical pencil broken experiment platform contains SAEU2S acoustic emission acquisition system is shown in Figure.17.

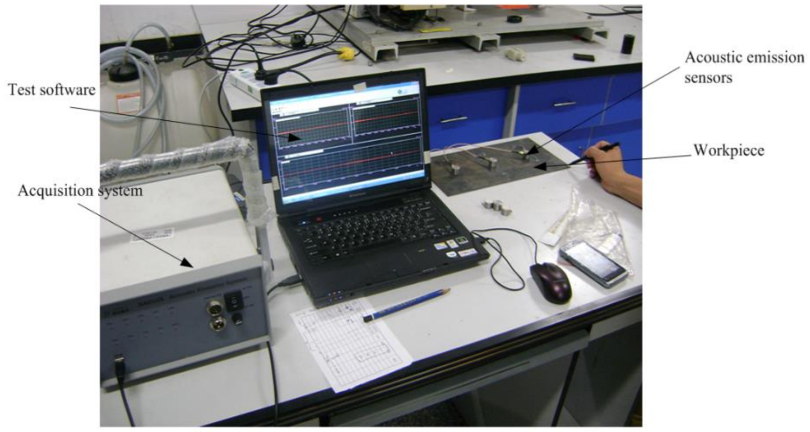
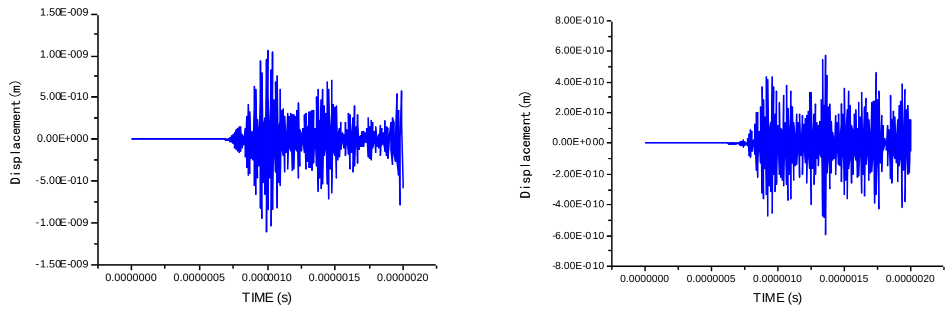


Figure 17. Mechanical Pencil Lead Fracture Experiment

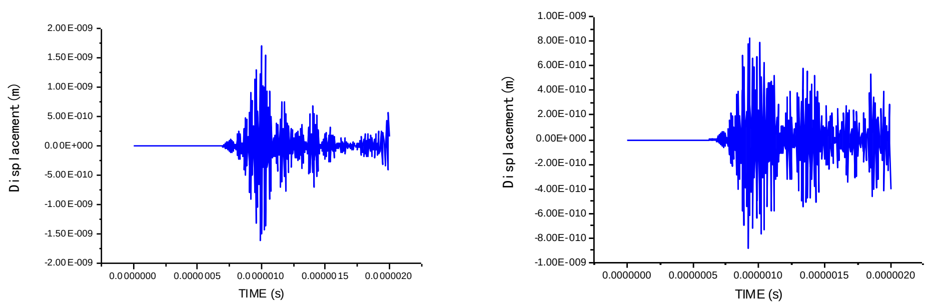
By comparing the collected acoustic signals from pencil broken experiment and simulation at the same position find that similarities between the two is very high ,which verified the accuracy and reasonableness of using acoustic emission signal simulation to study the propagation characteristics.

Figures.18 is the displacement waveform in plate from four sound source by simulation and experiment.



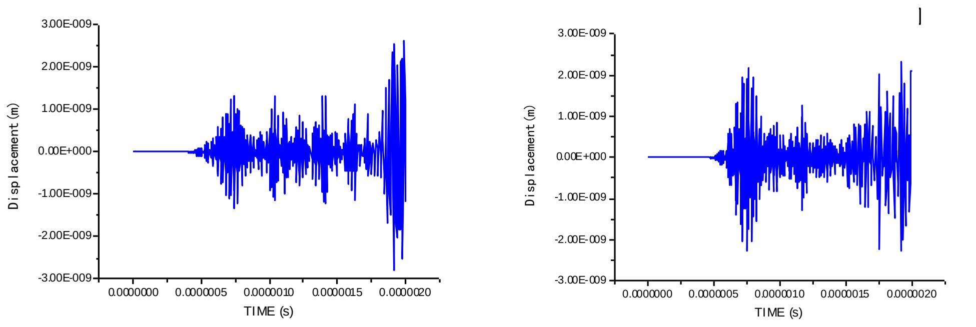
Simulation Waveform Experimental Waveform

(a) The Displacement Waveform from the First Sound Source Simulation and Experiment



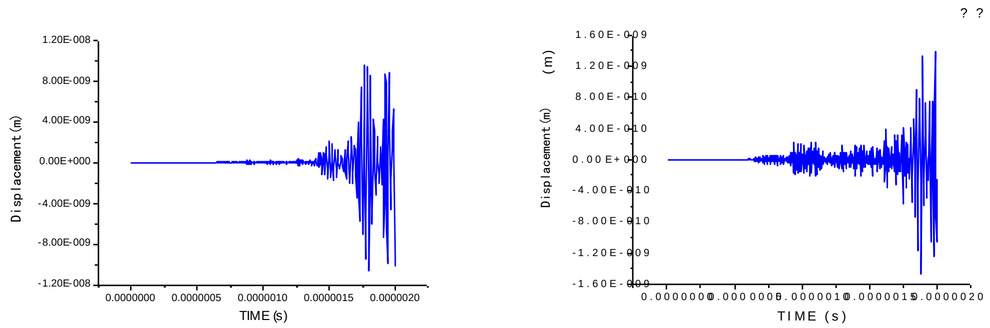
Simulation Waveform Experimental Waveform

(b) The Displacement Waveform from the Second Sound Source Simulation and Experiment



Simulation Waveform Experimental Waveform

(c)The Displacement Waveform from the Third Sound Source Simulation and Experiment



Simulation Waveform Experimental Waveform

(d) The Displacement Waveform from the Fourth Sound Source Simulation and Experiment

Figure 18. The Displacement Waveform from the Four Sound Source by Simulation and Experiment

By comparing the received waveform from four different sound sources at the same time, we can see the acoustic emission propagation from four different sound source becomes very complicated after attenuating. The propagation characteristics of the sound source 1,2,3 are similar, significantly different from the propagation characteristics of 4th sound source, the reason is the elastic wave from sound source 1,2,3 are plane wave propagation in the boundary with more pronounced refraction and reflection phenomenon.

6. Conclusion

In this paper, the finite element method is applied to study the propagation characteristics of acoustic emission elastic wave in structure with various materials and multilayer medium. In the plate structure with various materials, the velocity of longitudinal wave is faster than shear wave, but the amplitude of shear wave is relative large. The propagation of acoustic emission elastic wave occurs obvious emission and diffraction when it reaches the crack face and the boundary of the plate, the influence of diffraction also lead to dispersion of waveform. The presence of coating metal dielectric interface will direct affect the propagation of acoustic emission elastic waves. The phenomenon of refraction and diffraction will appear due to the interference of the media interface, and only a small amount of wave spread into the other layer. Finally the accuracy and reasonableness of the simulation of elastic wave propagation in plate structure is verified by the pencil broken experiment of four different sound source positions.

Acknowledgements

This work is supported by National Natural Science Foundation of China (51475159), is gratefully acknowledged.

References

[1] A. Livne, E. Bouchbinder and J. Fineberg, “Break down of linear elastic fracture mechanics near the tip of a rapid crack”, Phys. Rev. Lett., vol. 101, **(2008)**, pp. 264-301.
[2] A. Livne, E. Bouchbinder, I. Svetlizky and J. Fineberg, “The near-tip fields of fast cracks”, Science. vol. 327, **(2010)**, pp. 1359-1363.
[3] M. Buehler and H. Gao, “Dynamical fracture instabilities due to local hyperelasticity at crack tips”, Nature, vol. 439, **(2006)**, pp. 307-310.
[4] J. Fineberg, S. P. Gross, M. Marder and H. L. Swinney, “Instability in dynamic fracture”, Phys. Rev. Lett., vol. 67, **(1991)**, pp. 457-460.
[5] C. Große and M. Ohtsu, “Acoustic Emission Testing in Engineering: Basics and Applications”, Springer Verlag, Berlin, **(2008)**.
[6] M. R. Gorman, “Plate Wave Acoustic Emission”, Journal Acoust. Soc. Am., vol. 90, no. 1, **(1991)**, pp. 358-364.
[7] M. R. Gorman and W. H. Prosser, “AE Source Orientation by Plate Wave Analysis”, Journal Acoustic Emission, vol. 9, no. 4, **(1991)**, pp. 283-288.
[8] S. M. Ziola and M. R. Gorman, “Source Location in Thin Plates Using Cross-Correlation”, Journal Acoust. Soc. Am., vol. 90, no. 5, **(1991)**, pp. 2551-2556.
[9] M. R. Gorman and S. M. Ziola, “Plate Waves Produced by Transverse Matrix Cracking”, Ultrasonics, vol. 29, **(1991)**, pp. 245-251.
[10] W. H. Prosser, K. E. Jackson, S. Kellas, J. McKeon and A. Friedman, “Advanced Waveform Based Acoustic Emission Detection of Matrix Cracking inComposites”, Materials Evaluation, vol. 53, no. 9, **(1995)**, pp. 1052-1058.
[11] Z. You, “Review of Progress in Quantitative Nondestructive Evaluation”, New York:Plenum7A, **(1987)**, pp. 23-30.
[12] Z. You, M. Lusk, R. Ludwig and W. Lord, “Numerical simulation of ultrasonic wave propagation in anisotropic and attenuative solid materials”, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 38-5, **(1991)**, pp. 436-445.
[13] K. M. A. Jaleel, N. N. Kishore and V. Sundararajan, “Finite element simulation of elastic wave propagation in orthotropic composite materials”, Materials Evaluation, vol. 51-7, **(1993)**, pp. 830-838.
[14] M. Hamstad, A. O’Gallagher, and J. Gary, “Modeling of buried acoustic emission monopole and dipole sources with a finite element technique”, Journal Acoust. Emiss., vol. 17, no. 3-4, **(1999)**, pp. 97-110.
[15] W. Prosser, M. Hamstad, J. Gary and A. O’Gallagher, “Comparison of finite element and plate theory methods for modeling acoustic emission waveforms”, Journal Nondestruct. Eval, vol. 18, no. 3, **(1999)**, pp. 83-90.
[16] M. A. Hamstad, A. O’Gallagher and J. Gary, “Modeling of buried acoustic emission monopole and dipole sources with a finite element technique”, Journal Acoust. Emiss., vol. 17, no. 3-4, **(1999)**, pp. 97–110.
[17] M. Sause and S. Horn, “Simulation of acoustic emission in planar carbon fiber reinforced plastic specimens”, Journal Nondestruct. Eval., vol. 29, no. 2, **(2010)**, pp. 123-142.
[18] P. Wilcox, C. Lee, J. Scholey, M. Friswell and M. Wisnom, “Drinkwater, B.: Progress towards a forward model of the complete acoustic emission process”, Adv. Mater. Res., vol. 13-14, **(2006)**, pp. 69–76.

Authors

Kuanfang He, He is male, born in November 13, 1979 in Chenzhou (Hunan, China). He has been gotten the bachelor degree of mechanical engineering in 1999, master degree of mechanical engineering in 2006, and PhD degree of mechanical engineering in 2009. Now he is associate professor of Hunan University of Science &Technology, focus on the research of dynamic monitoring and diagnosis of mechanical systems supported by National Natural Science Fund of China and Hunan Provincial Natural Science Foundation of China and so on. He has over 40 publications as author and co-author in (Measurement), (Journal of Intelligent Manufacturing), (Materials Research Innovations) and (Journal of Advanced Mechanical Design, Systems, and Manufacturing), and owns 10 authorized patents and software copyrights, 6 items of Science and Technology Awards.

