氏名	LI RAN
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学位論文題目	Dynamic analysis of ultrasonic wave propagation in composite materials and its application for damage evaluation （複合材料における超音波伝播解析及び損傷評価への応用）
論文審査委員	主査　教　授　倪　慶清 准教授　夏木　俊明 教　授　小西　哉 教　授　石澤　広明 教　授　呉　景龍　（岡山大学）

論　文　内　容　の　要　旨

In this work, for giving guidance to the further development of high-precision ultrasonic technology in material characterization and defect detection for composite materials, a series of unique approaches are proposed. By means of time-domain finite element analysis of ultrasonic wave propagation in both of fiber- and particle-reinforced composite materials, the dynamic internal stress distribution which is tightly corresponding to the ultrasonic wave propagation behavior is visualized and analyzed. With consideration of the influences of various factors, such as: material viscoelasticity and anisotropy, internal microstructures and defects, interfacial conditions between constituent phases, incident wave characteristics, each individual wave component and corresponding attenuation component are separately and systematically investigated. On the basis of above studies, the detailed influence mechanisms of aforementioned factors on ultrasonic wave propagation, attenuation characteristics and material viscoelastic properties are clarified.

1) A new method to evaluate dynamic stress distribution of composite materials is proposed by using ultrasonic wave propagation analysis. In the method, a two-dimensional bimaterial composites with elliptical defect is modeled by using the finite element analysis code, “PZflex”. During the ultrasonic wave propagation, the deformation of the composites model and the internal dynamic stress distribution are visualized and investigated. The influences of material anisotropy on wave propagation are took into consideration, by changing the elastic modulus ratio between fiber and matrix layer, E_f/E_m. Under different anisotropic properties, the influences of stress singularities at defect tips and the free edge of interface, as well as the waveform conversion at interface, on ultrasonic wave propagation and internal stress distribution are evaluated. The simulation results showed that, the method using ultrasonic wave propagation analysis is a convenient and effective way to study the interrelationship among the material properties, internal microstructures and defects, and dynamic internal stress distribution in composite materials.

2) When ultrasonic waves propagate in composite materials, the attenuation characteristics result from the combination effects of various factors, such as material anisotropy and viscoelastic

property, internal microstructure and interfacial conditions, incident wave characteristics and so on. Based on the aforementioned method for analyzing the dynamic internal stress distribution, the detailed influence mechanisms of the above factors on ultrasonic wave attenuation characteristics are investigated. In this chapter, a unique approach is proposed, in which each attenuation component can be extracted from the overall attenuation and separately discussed. The variation behaviors of each component against material anisotropy and matrix viscosity are separately and quantitatively evaluated. From the analysis results, the energy dissipation at fiber/matrix interface is a major component in ultrasonic wave attenuation characteristics, which can provide a maximum contribution rate of 68.2 % to the overall attenuation, and each attenuation component is closely related to the material anisotropy and viscoelasticity.

3) Based on the aforementioned methods, a further study with consideration of the frequency characteristics of each individual attenuation component is carried out. In this chapter, based on the two-layered fiber/matrix composite materials model, by means of extracting the individual attenuation components (viscoelastic attenuation, scattering attenuation due to interfacial defects, and energy dissipation at the interface) from the overall attenuation respectively, the frequency characteristics of each of them with consideration of different material anisotropy and viscoelasticity are quantitatively evaluated. From the results, the ultrasonic wave attenuation during the propagation in layered composite material is mainly due to the matrix viscosity and interfacial interactions, and all attenuation components represent frequency dependence. At low frequencies, energy dissipation at the interface is the main content of the overall attenuation, then the material viscoelastic properties. At high frequency, the effect of the matrix viscosity on the overall attenuation became more significant. Through the present analysis, we can quantitatively evaluate the detailed correlation between the various effect factors and the individual ultrasonic attenuation components, especially the frequency characteristics.

4) The work in this chapter is dedicated to the practical ultrasonic testing experiment, which is for evaluating the dynamic mechanical characteristics of particle reinforced composite materials. Through a unique material evaluation method, Ultrasonic Dynamic Mechanical Analysis (U-DMA), the dynamic viscoelasticity of particulate composites with different types and contents of particles are measured directly in high frequency domain. In order to clarify the influence mechanisms of distributed particles, on the basis of proposed methods, the ultrasonic wave propagation behaviors due to multi-reflection and scattering waves by particles and matrix viscoelasticity, especially the mutual interactions among particles, are systematically investigated. The individual wave components and attenuation components are also separately and quantitatively discussed. The results clarify that the interactions among particles are playing a major role in ultrasonic wave propagation and attenuation properties, which can significantly affect the viscoelastic characteristics of developed materials. The feasibility and effectiveness of U-DMA and the proposed methods are verified from both simulation and practical experiments.