Heterogeneous layered materials are vital in modern high-performance systems due to their ability to integrate distinct material phases, allowing for tailored mechanical, thermal, and dynamic properties. These materials outperform homogeneous systems, especially in energy absorption and damage resistance under extreme dynamic loads like impacts and blasts. However, despite progress in experiments and simulations, analytical understanding of wave propagation and damage evolution under high-strain-rate conditions remains limited, due to the complexities of heterogeneous architectures, impedance mismatches, and interfacial behaviour.

This thesis develops a comprehensive semi-analytical framework to investigate stress wave propagation, interaction, and damage evolution in layered heterogeneous media subjected to one-dimensional normal impact. A multi-linear constitutive model is employed to represent the uniaxial strain compressive behaviour of each layer, incorporating layer-specific elastic moduli, Hugoniot Elastic Limits (HEL), and shock impedances. The tensile response is modelled linearly, enabling accurate representation of spallation. The governing conservation laws for mass and momentum are formulated in the Lagrangian framework and combined with a maximally dissipative kinetic relation to uniquely resolve shock formation across interfaces. The study categorises the impact response as low-velocity impacts, which generate predominantly elastic wave propagation, and high-velocity impacts, which induce the formation of both elastic and shock waves. The proposed framework tracks wave interactions, systematically resolving the generation, reflection, and transmission of elastic, shock, and rarefaction waves across interfaces with varying wave impedance. It identifies and classifies novel interaction scenarios arising from material heterogeneity in terms of varying moduli, HEL and compressibility, such as various new wave formations upon an interaction. The response of the media is analysed using the stress and particle velocity variations at various locations within the media.

Wave interactions in heterogeneous media can generate tensile stresses that may initiate internal damage or interfacial failure, referred to as spall damage. A strain-based damage model is integrated to capture the initiation and progression of damage, accounting for the degradation of key material parameters such as elastic modulus, wave speed, and HEL. The damage model constrains the maximum damage value to limit the study to incipient damage states. The study presents comparative analyses between damaged and undamaged cases for both single- and multi-layered target configurations. The results demonstrate that the evolution of damage significantly influences the wave propagation characteristics, leading to stress attenuation, delayed arrival times, and complex wave patterns. The findings indicate that damage can initiate from internal wave interactions and through the interface between layers with varying impedances, not solely from free-surface reflections. Additionally, the role of HEL mismatch, impedance gradients, and strain-dependent moduli is shown to be critical in governing the conditions under which spallation occurs. The semi-analytical predictions are validated against finite element simulations performed in ABAQUS. The material behaviour and damage models are implemented through VUMAT and VUEOS subroutines. The high degree of correlation between analytical and numerical results confirms the accuracy of the developed framework.

Overall, this thesis provides a generalised and robust semi-analytical tool for understanding and predicting wave-induced damage in layered heterogeneous materials under dynamic loading. It fills a crucial gap in existing modelling approaches by explicitly coupling wave mechanics with progressive damage evolution, offering deeper insight into spallation and dynamic failure