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Recent Advances in Dynamic Failure Research (Keynote//S06-Dynamic Response Behavior)

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Composite materials are used increasingly in a wide variety of applications, including sporting goods, civil infrastructure, automotive structures, aerospace structures, ship structures, and offshore structures. Newer applications give rise to research issues and technological challenges not encountered in aerospace applications of composites. The area of the dynamic response and dynamic failure of composites remains one of the most exciting areas of research in composites. Major advances in dynamic response and dynamic failure research have been made recently; these advances will be covered in this presentation.

The Office of Naval Research has established a comprehensive research program on composite structures, to provide the scientific basis for the effective design and use of polymer matrix composites in advanced structures. A major component of this research program is dynamic failure research, encompassing the establishment of dynamic constitutive equations, strain rate effects, dynamic failure modes, dynamic failure criteria, dynamic structural response and quantitative non-destructive evaluation. An overview will be provided of the dynamic failure research program, including research issues, objectives, recent accomplishments, and future directions.

Examples of the use of composite materials in different types of structures will be provided, including ship hulls and ship topsides. Monolithic composite hulls for mine-hunters, and an advanced stealth ship built using carbon fiber composites and foam core sandwich construction will be discussed. The unique harsh marine environment, with dynamic wave loading, and its implications for marine structures will be discussed. The effects of moisture, seawater, hydrostatic pressure, and temperature variations on composites, will also be discussed.

The establishment of three-dimensional dynamic constitutive equations for composites, and their strain rate dependence, utilizing several experimental methods will be described. Dynamic constitutive models to predict the three-dimensional nonlinear rate dependent behavior of unidirectional and woven fiber reinforced composites have been developed. The effect of confining pressure on the dynamic compressive strength and dynamic failure modes has been established.

Innovative experimental methods will be described for the real-time delineation of dynamic failure events in composites. The optical Coherent Gradient Technique, providing full field deformations, coupled to high-speed photography, with one hundred million frames per second capability, has been used to elucidate the physical processes involved in the dynamic failure of composites. Real time investigations of dynamic Mode I fracture will be described showing the evolution of dynamic deformation fields and crack propagation speeds. The

Mode I dynamic fracture toughness and its dependence on loading rate have been established. Crack speeds do not exceed the Rayleigh wave speed or the shear wave speed. Innovative experimental techniques for dynamic Mode II fracture studies have also been developed. Real time investigations of Mode II fracture under dynamic shear loading conditions have revealed the existence of crack speeds in excess of the Rayleigh wave speed, and approaching the dilatational wave speed. In this case, the evolution of the deformation fields and the formation of shock fronts have been established. The surprising phenomenon of intersonic crack growth has proven to be one of the most exciting areas of research in solid mechanics.

This research program has shown the importance of accounting for thermodynamic effects during dynamic failure of solids. Infrared sensor arrays have been developed and utilized for the mapping of thermal fields in the vicinity of dynamic fracture surfaces. The evolution of these dynamic thermal fields, and their implications for failure theories, will be discussed. Although in metals, crack tip temperatures exceeding 1000 degrees Celsius have been measured, much smaller temperature have been measured in composites.

Impact damage in composite materials has been studied. Methods have been developed for determining the onset and evolution of dynamic delamination in composites. Real time studies of dynamic delamination have enabled the estimation of dynamic delamination growth speeds, for the first time. The loss of compression strength after impact has been studied, and models for the prediction of post-impact compression strength will be presented.

Sandwich construction is utilized in many advanced marine structures, with composite face sheets and PVC foam core or balsa wood core. The dynamic response of these composite sandwich structures, as well as the response of the core materials, have been established. Impact damage in sandwich structures and compression strength after impact have been investigated, and methods have been developed for mitigating impact damage.

Nondestructive methods will be described for the detection and estimation of defects and damage in composite materials and composite sandwich structures. These include ultrasonic based techniques, as well as vibration based methods. Ultrasonic based techniques have been developed for the detection and estimation of fiber/ply waviness in thick composites, as well as face-core debonds in composite sandwich plates with foam cores.

The research program described here utilizes an integrated approach, with close coupling between advanced theories, innovative experiments, and computational methods, for the elucidation of the dynamic response and dynamic failure of composite materials and structures, and for the establishment of physically based theories and models. The presentation will conclude with a discussion of research needs and future research directions.