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DEVELOPMENT OF A NOVEL CERAMIC ARMOR SYSTEM: ANALYSIS AND TEST

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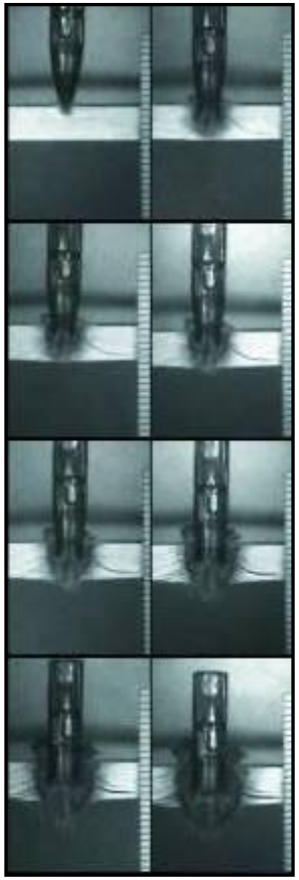
•Optimization of new armor systems must be underpinned by a fundamental understanding of high strain rate dynamic events and subsequent material response and failure mechanisms during the impact and penetration event.



•Development of hybrid armor systems frequently feature combinations of hard ceramics, composites, and metallics in tailored configurations seeking to optimize ballistic performance, weight, volume, and cost.

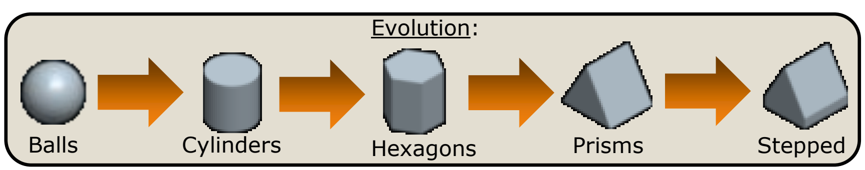
•The complexity of the physics during the ballistic event makes isolation of armor system key performance parameters difficult, involving mechanisms such as penetrator fracture or blunting, penetrator erosion, loading of armor elements, fracture of armor elements, loading of (and erosion due to) the resulting rubble bed, momentum transfer, ejection of debris, shock and stress wave propagation and interaction, and residual kinetic energy absorption.

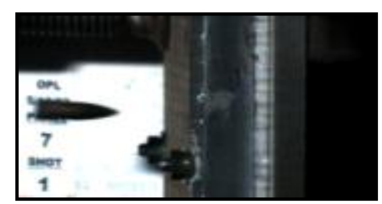
• Armor system design must consider each of these mechanisms for increased efficiency.

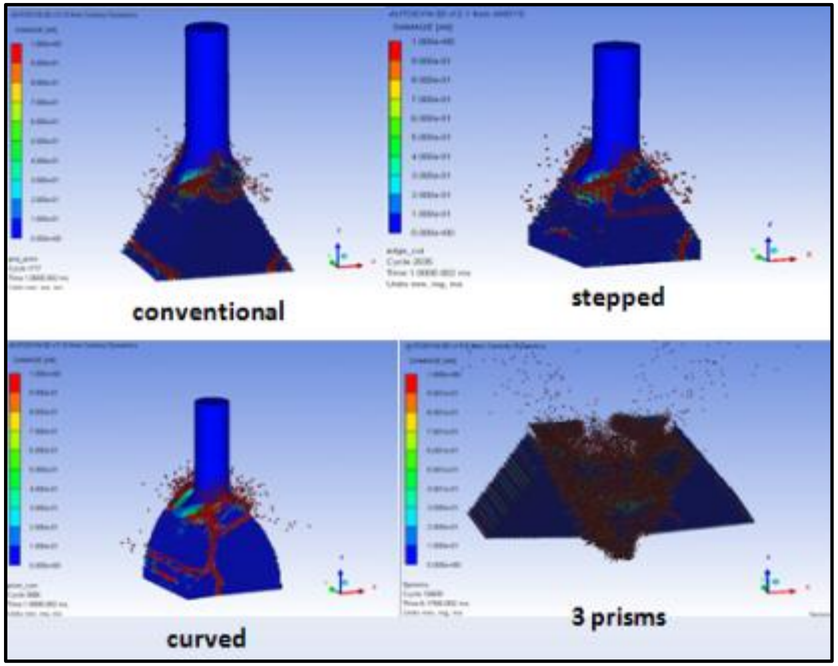
•Our approach focused on use of discrete embedded ceramic elements (threat defeat, multi-hit and crack arresting improvements), of specific shape and size (shock wave control, rubble bed confinement, threat defeat), separated by low impedance polymers (shock wave and crack control) with suitable cover plates and back-up plates (rubble confinement, dwell increase, momentum transfer).

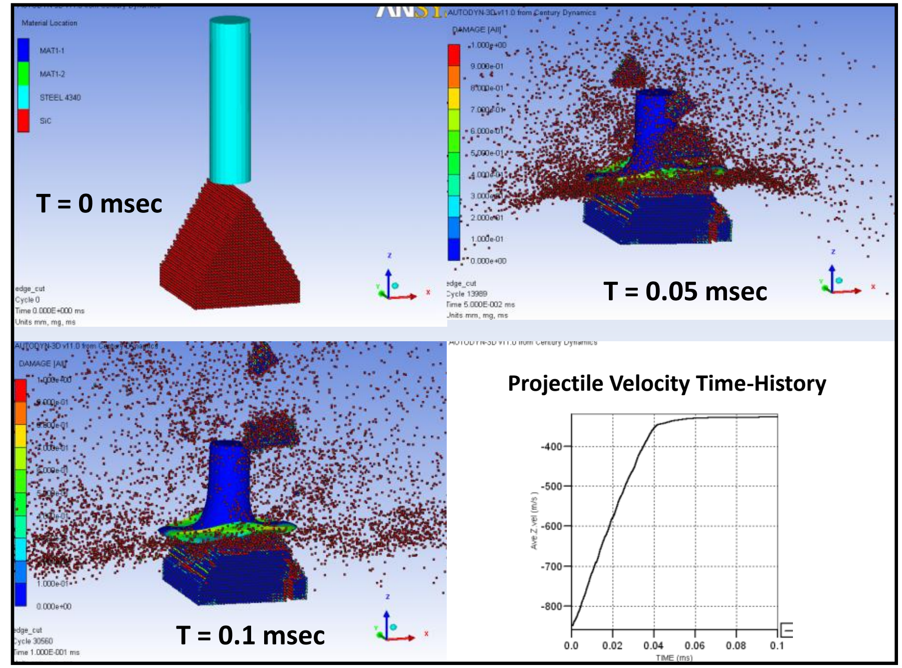
•Development was guided by and relied heavily on judicious use of analytical predictions correlated with ballistic testing and post-test failure morphology investigations.

•Our approach started with single element studies, followed by multi-component modeling, which were then followed by full armor system modeling. The bulk of our analysis used phenomenological modeling approaches (finite element, particle dynamics and mixed finite element-particle formulations).







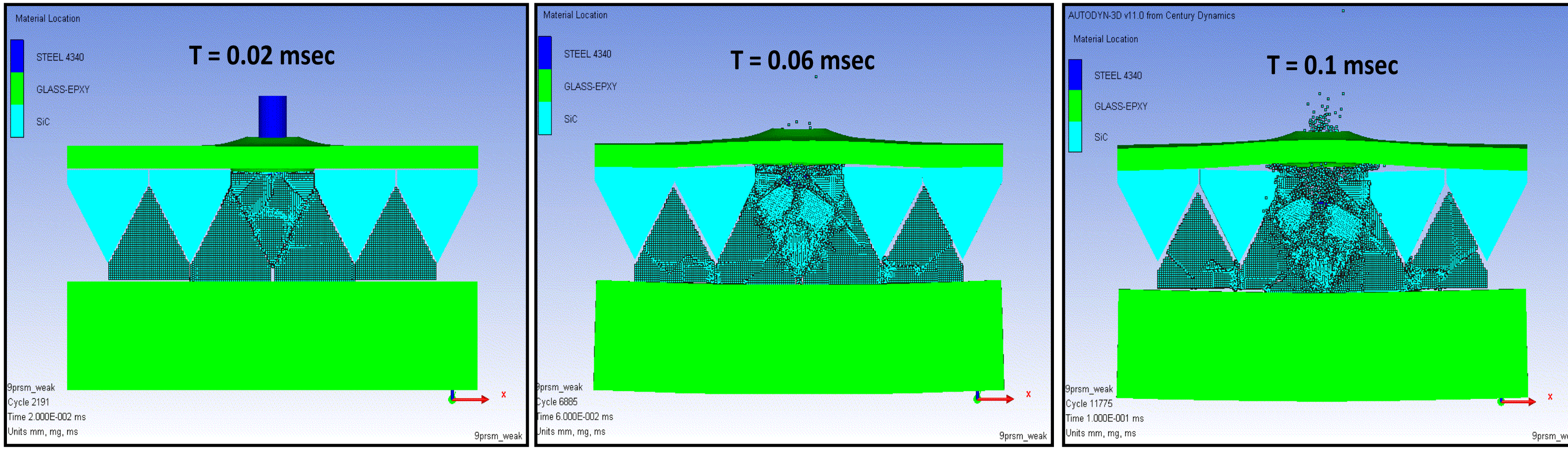


- Single element studies guided ceramic element shape optimization.

- Crack development was studied under representative penetrator impacts

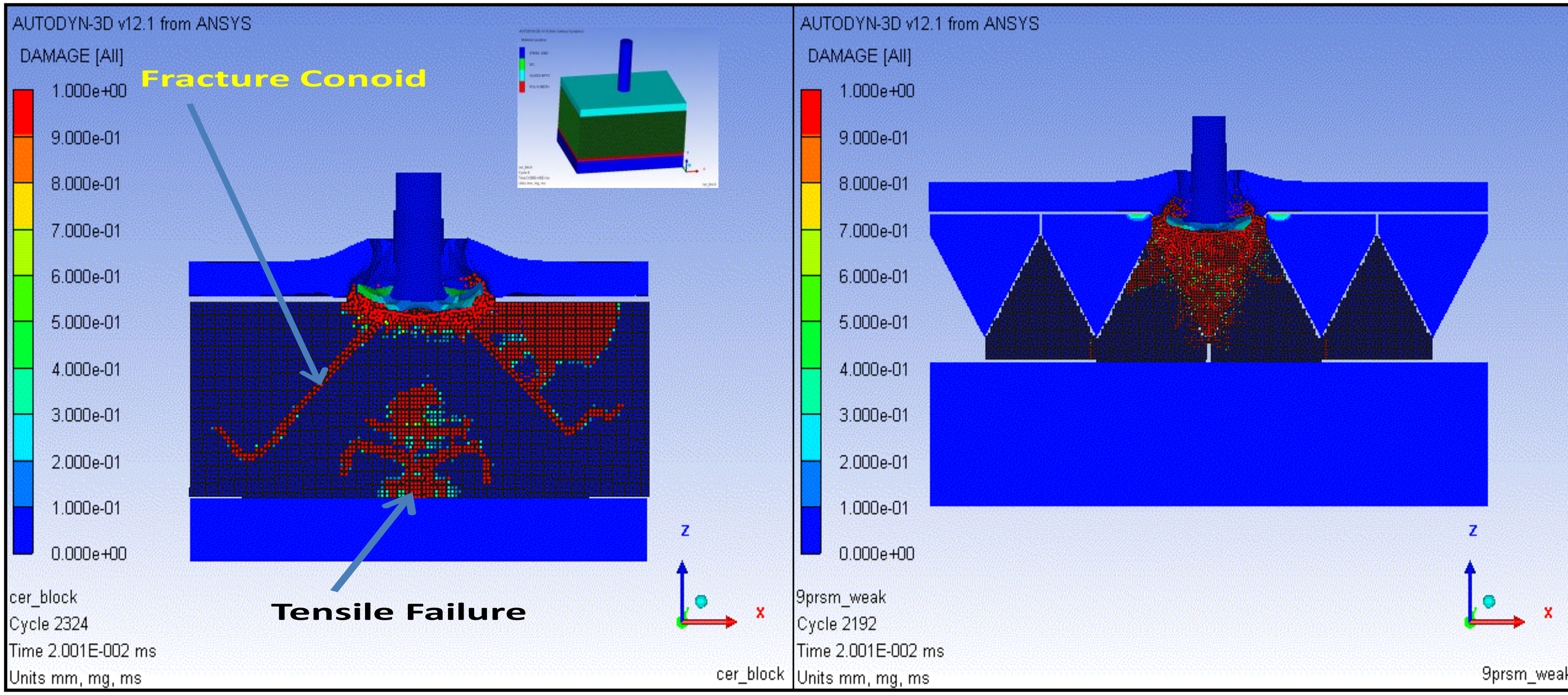
- Ceramic prism is modeled with smooth particle hydrodynamics (SPH); both JH-1 and JH-2 were used. JH-1 showed significantly better correlation with test results, and was used in remaining studies.

- Projectile modeled with regular finite elements, with Johnson-Cook strength and fracture format.



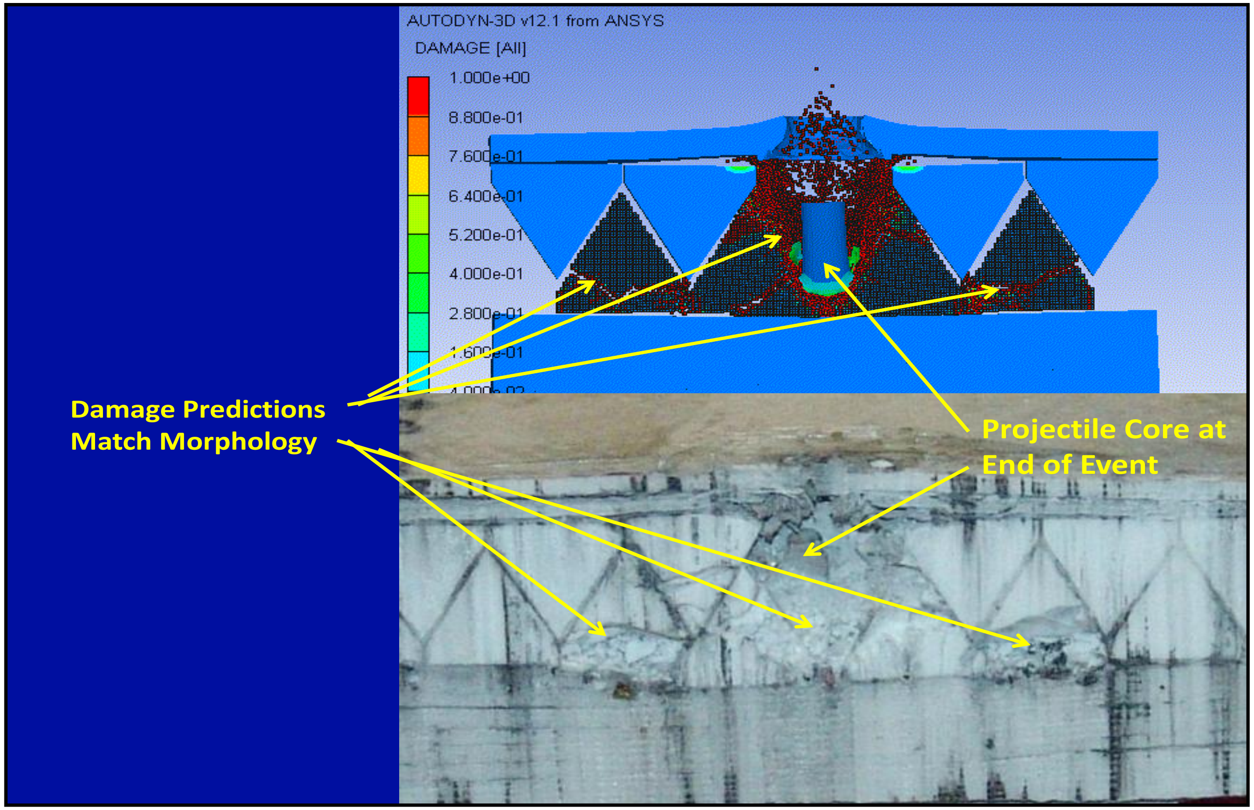
- Modeling complexity progressed to multi-component models to predict interaction of various numbers of stacked prisms coupled with strike and back plates.

- SPH technique is well suited for capturing crack propagation, but is computation intensive for accurate solutions. Our approach combined SPH with finite elements; the prisms which undergo minimum damage are modeled with finite elements; and the prisms which undergo extensive damage are modeled with SPH particles

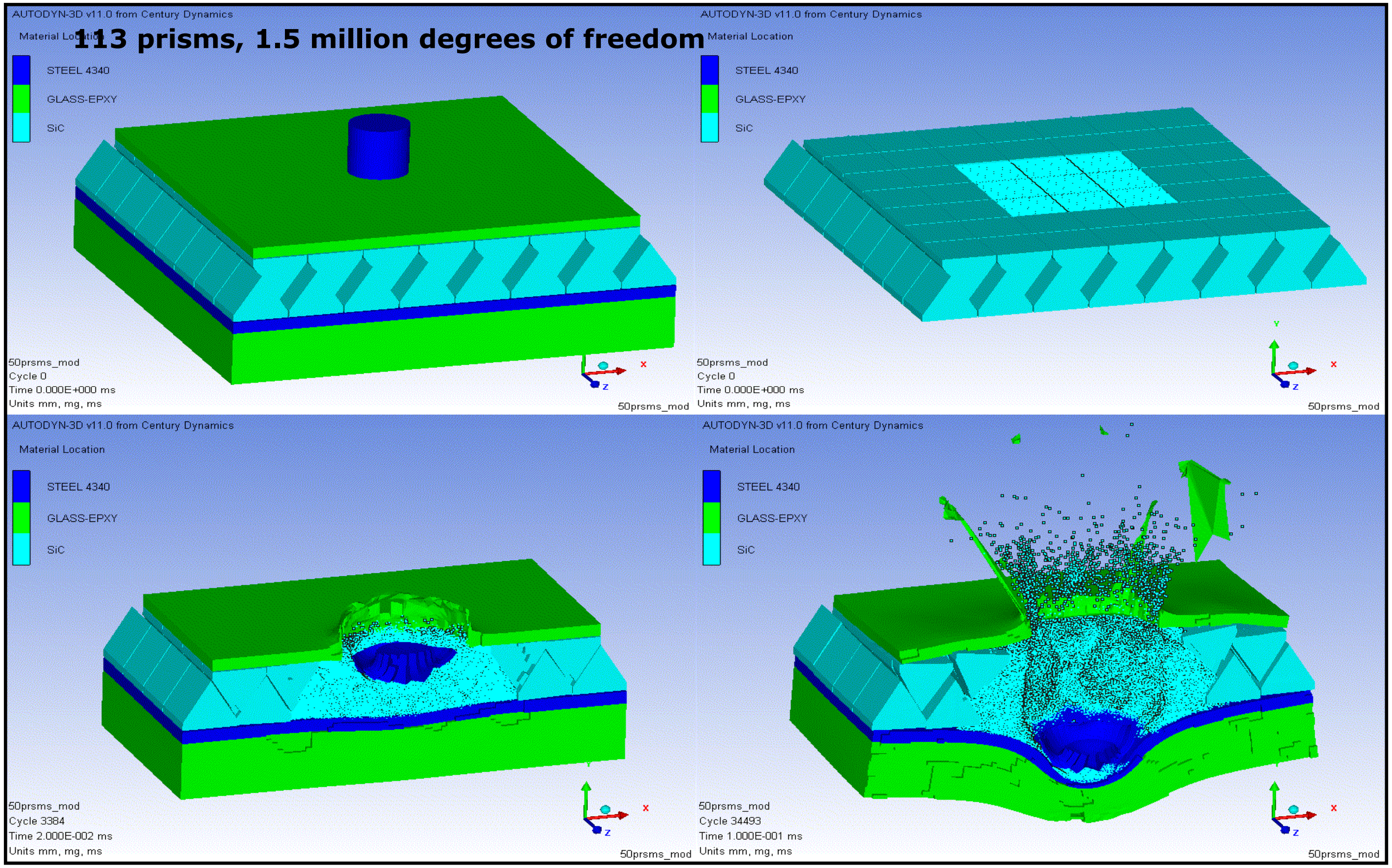


- Comparison of the damaged zone in a monolithic ceramic tile to that of the prism configuration

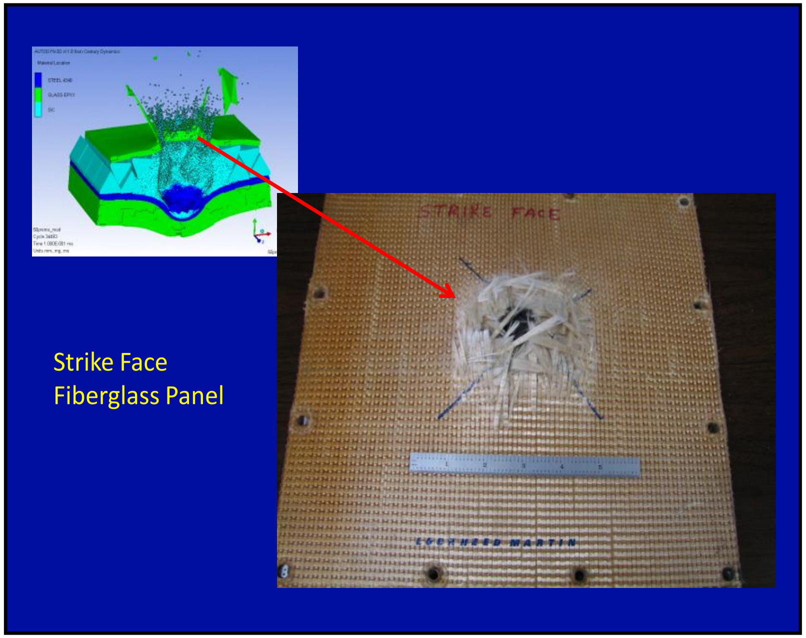
- Analysis of the velocity time-history of the projectile as it penetrates these prismatic architectures shows multi-stage behaviors, which can be attributed to different mechanisms, including physical confinement of the pulverized rubble bed by neighboring prisms leading to increased erosion of the penetrator as it progresses through the laminate.

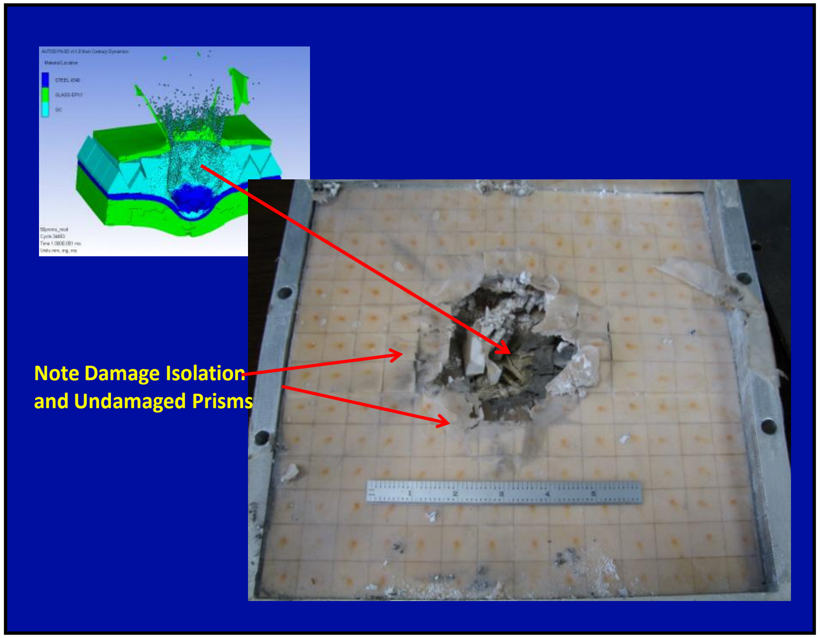


•Ballistic Test Correlation: Damage prediction correlates well with dissected test panels with respect to the pattern and extent of the damage. The containment of the projectile core is also well predicted

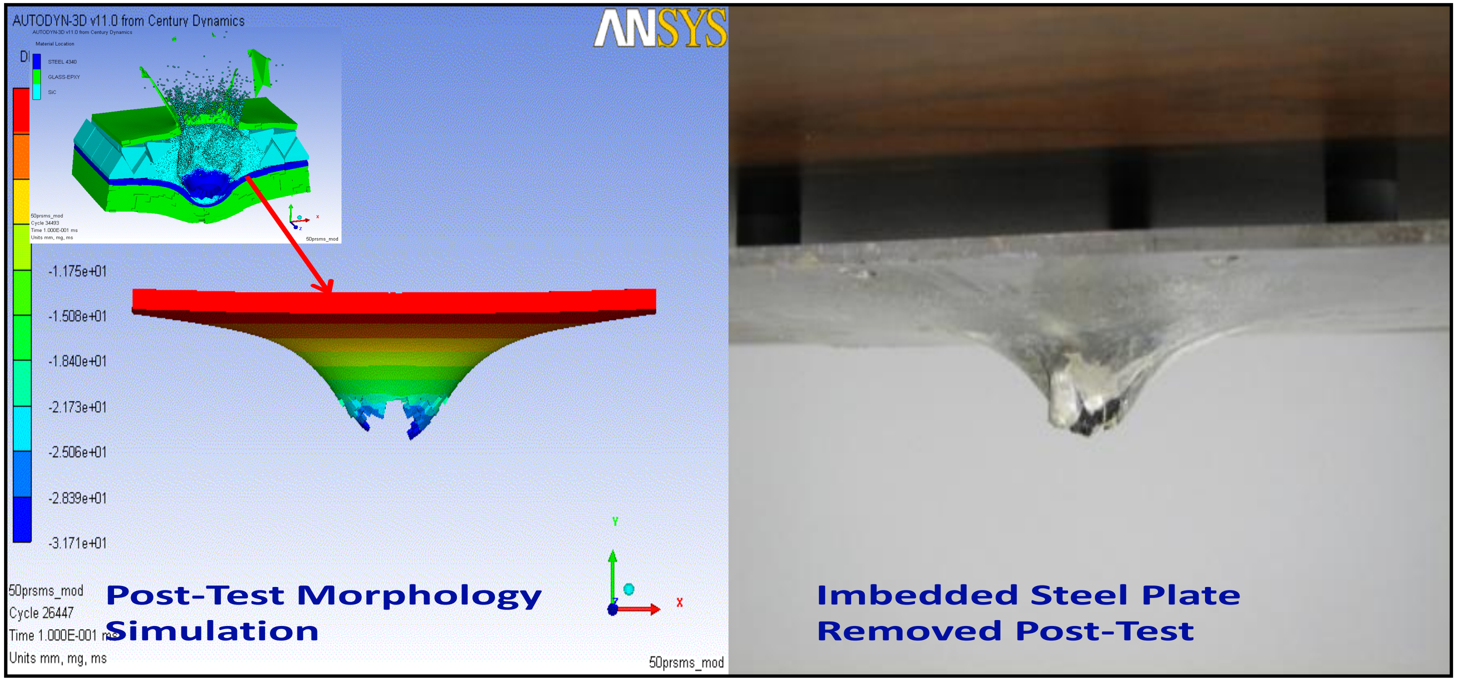


•From the multi-component model, "full armor" models were developed for further increases in simulation fidelity which are closely representative to tactically relevant armor architectures. These full models are used to examine global armor responses to different threats, including larger bullet threats and high speed fragment impacts

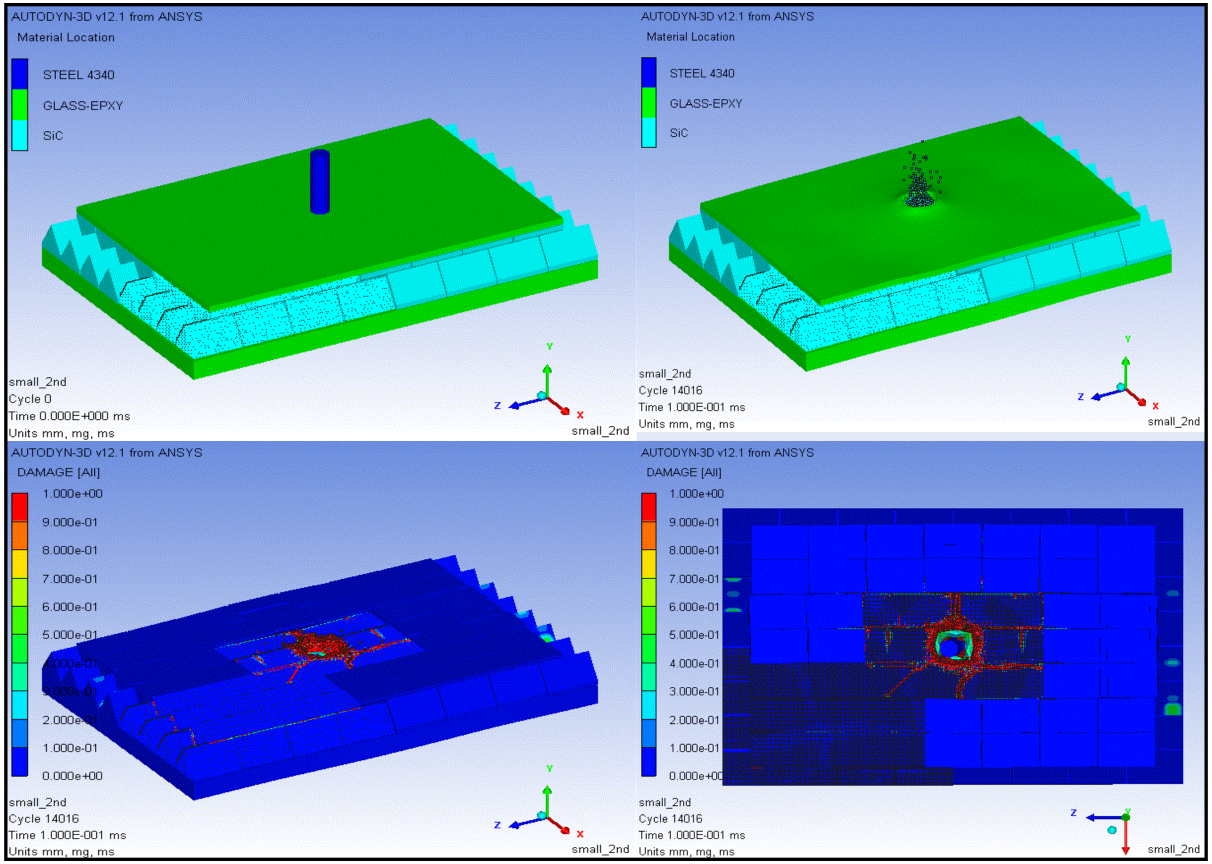




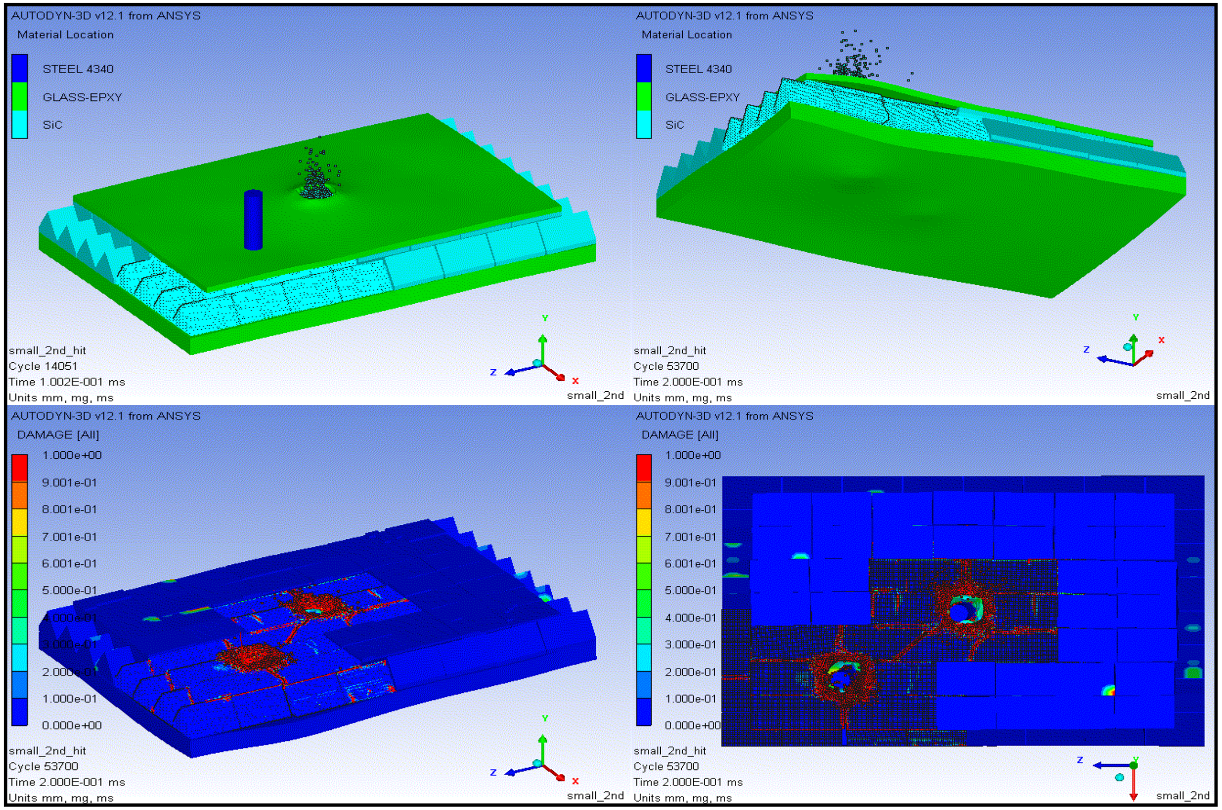
- Panels were built and ballistically tested to examine the failure morphology and ballistic predictions. The numerical predictions correlate well with the damage pattern.



- Numerical simulation of damage to embedded steel plate compares well with the post-test plate morphology

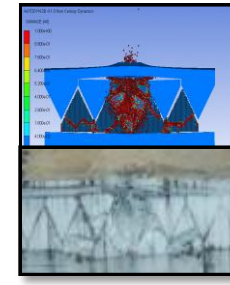


•Multi-strike modeling in work: Numerical simulation of ceramic armor impacted by 1st projectile and damage sustained on ceramic array after the event



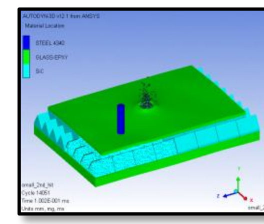
•Numerical simulation of 2nd projectile impact on ceramic armor and damage sustained on ceramic array after the event. Multi-strike capability prediction confirmed by ballistic tests.

Summary and Conclusions



•Fundamental work has been performed developing novel armor topologies that consider shock, dwell, erosion, and subsequent penetration time history to guide armor architecture configurations.

•Results are presented for an advanced ceramic armor system consisting of three dimensional arrays of nested ceramic prisms exhibiting high ballistic performance and multi-strike capability.



•Development was guided by and relied heavily on judicious use of analytical predictions correlated with ballistic testing and post-test failure morphology investigations.

•Test results substantially confirmed the numerical predictions for the projectile containment, the damage propagation through the array of prisms and the extent of the damaged zone in the armor system.

•The effective use of these simulation approaches is limited by the ability to obtain deformation results independent of discretization and very high strain rate material characteristics. For these reasons we are currently extending our work to incorporate microphysical/physics based models as they mature.

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