A Computational Study of the Energy Dissipation Through an Acrylic Target Impacted by Various Size FSP

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

OUTLINE

- *Objective*
- *Background*
- *Experimental Details*
- *Numerical Simulations*
- *Regression Analysis*
- *Summary*
- *Future Plans*

Knowledge of the energy absorption by an impacted material is a necessary requirement for the successful design of an armor

Objective

- To study the energy dissipation through acrylic targets of varying thickness and architecture impacted by various size Fragmented Simulated Projectiles (FSPs)
- To produce analytical expressions of the velocity profiles by using regression analysis tools in an effort
  - to produce a general equation of energy absorption of a projectile through a PMMA target

et Penetration Factors

- According to M . L. Wilkins et al* ñThe important projectile parameters for target penetration are geometry, material strength, density, and velocity.
  - Geometry refers to the sharp point used in the design of armor piercing projectiles.
  - Material strength is the parameter that permits the projectile to maintain the designed armor-piercing shape during the penetration process.
  - The projectile material strength is important until a target that is stronger than the projectile is encountered.
    - Then, the penetration process is governed by the projectile mass and velocity.
      - For example, ball and armor piercing, and projectiles with the same mass have about the same ballistic limit for ceramic targets strong enough to destroy the tip of the armor piercing projectile.ò

*M: L. Wilkins, R. L. Lamdingham, C. **A.** Honodel, Fifth Progress Report of Light Armor Program, UCRL-50980, University of California, Liveromore.

Background

Å Commercially available transparent armor systems are used in a variety of military and civilian applications including

ï face shields, goggles, vehicle vision blocks, windshields and windows, blast shields, and aircraft canopies

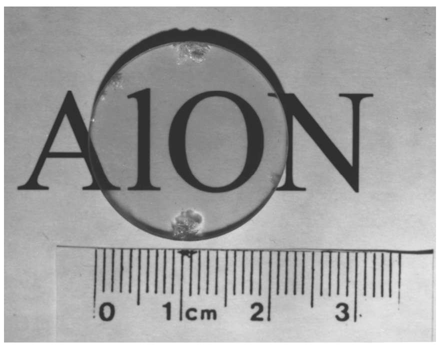
Å High performance transparent armor systems typically consist of several different materials, such as

ï PMMA, float or soda lime glass, sapphire, ALON, spinel, and polycarbonate bonded together with a rubbery interlayer such as polyurethane (PU) or polyvinylbutyral (PVB),

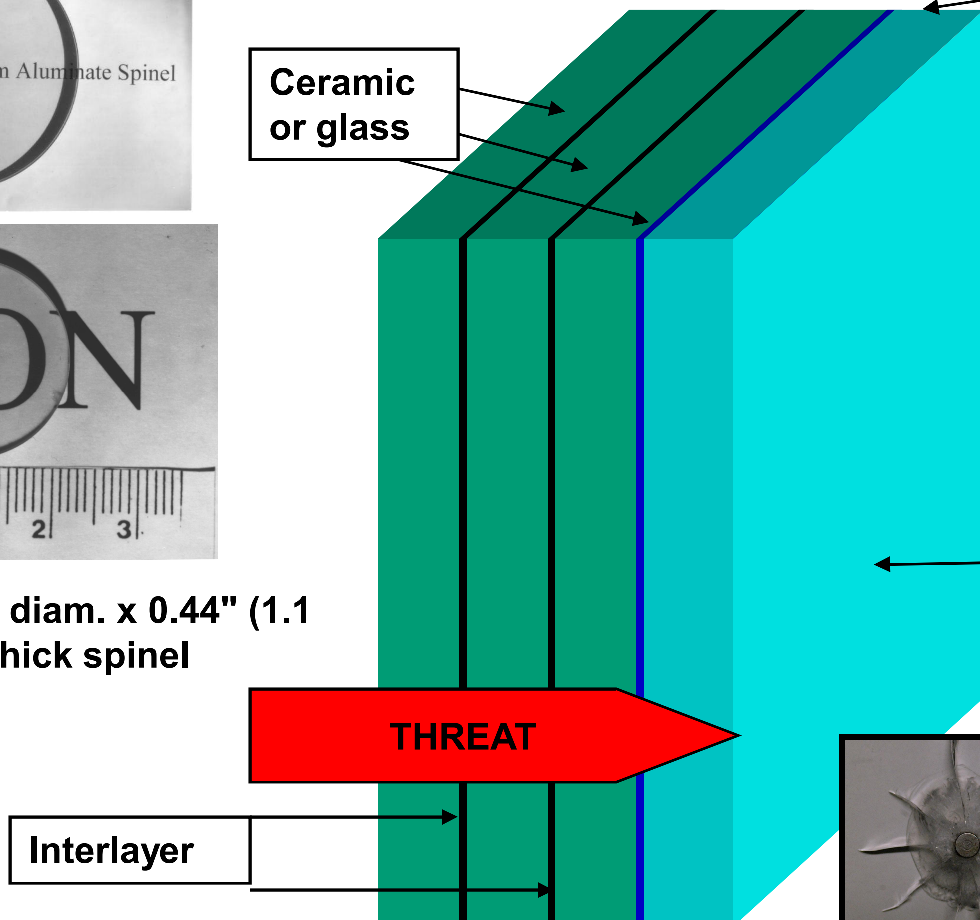
Å The lamination sequence, material thicknesses and bonding between layers has been shown to drastically affect system performance and it has been observed that each material serves an important function.

...sparent Armor Design

0.12”(3 mm) thick
85.2 % transmittance

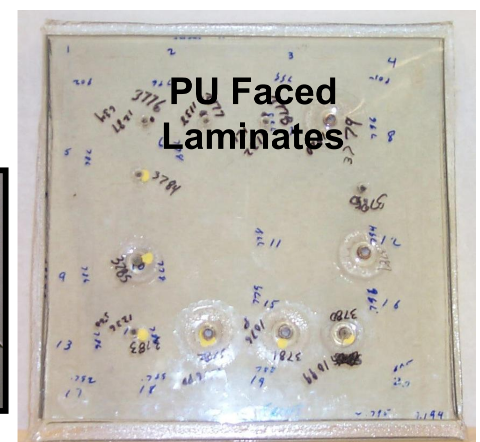


4” (10.2 cm) diam. x 0.44" (1.1 cm) thick spinel



Interlayer between polycarbonate

Polymer backing



Modeling Efforts

Å Numerical simulations coupled with experiments provide a more cost-effective way of studying the ballistic performance of monolithic and laminated transparent armor systems

Å Accurately simulating polymeric transparent armor material over a range of strain rates has proven challenging

ï Nandlall and Livingstone established that by adjusting the element erosion strain, the constitutive model was capable of accurately simulating the experimental ballistic limits

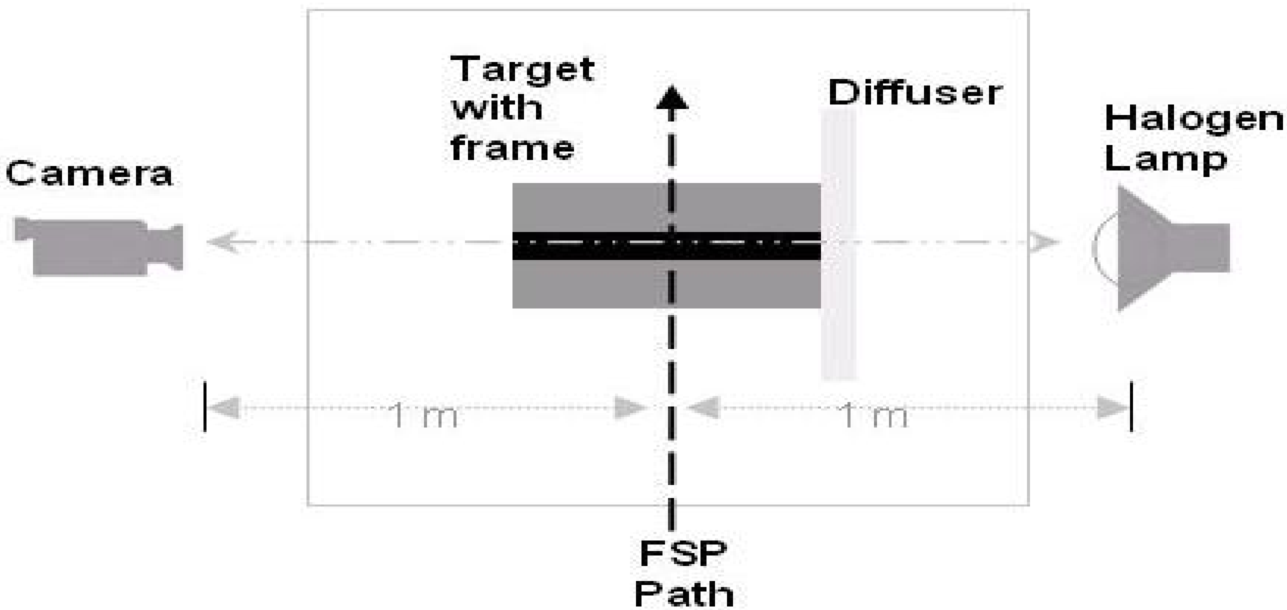
Å Recent development of constitutive equations combining nonlinear viscoelasticity and viscoplasticity capture most of the time-dependent, nonlinear response observed for glassy polymers

xperimental Details

- Ballistic measurements were carried out at the Experimental Facility of Aberdeen Proving Ground, MD, using a 17-gr (1.1-g weight) .22-cal FSP, and a 5.85-gr (0.37 g weight) .15-cal FSP
- The cross-section area of all the acrylic targets was 152.4-mm x 152.4-mm. The target architecture was
  - Monolithic targets of thickness 11.82-mm and 5.92-mm
    - They were impacted by .22-cal and .15-cal FSP respectively
  - A third target, which was consisted of two 5.92-mm thick plates of acrylic without any adhesive between them-total thickness of the set 11.84-mm-
    - It was impacted by a .22-cal FSP.
- All targets were sandwiched in a transparent frame
- All shots were conducted with the target normal to the projectile line of flight, i.e., 0° obliquity.

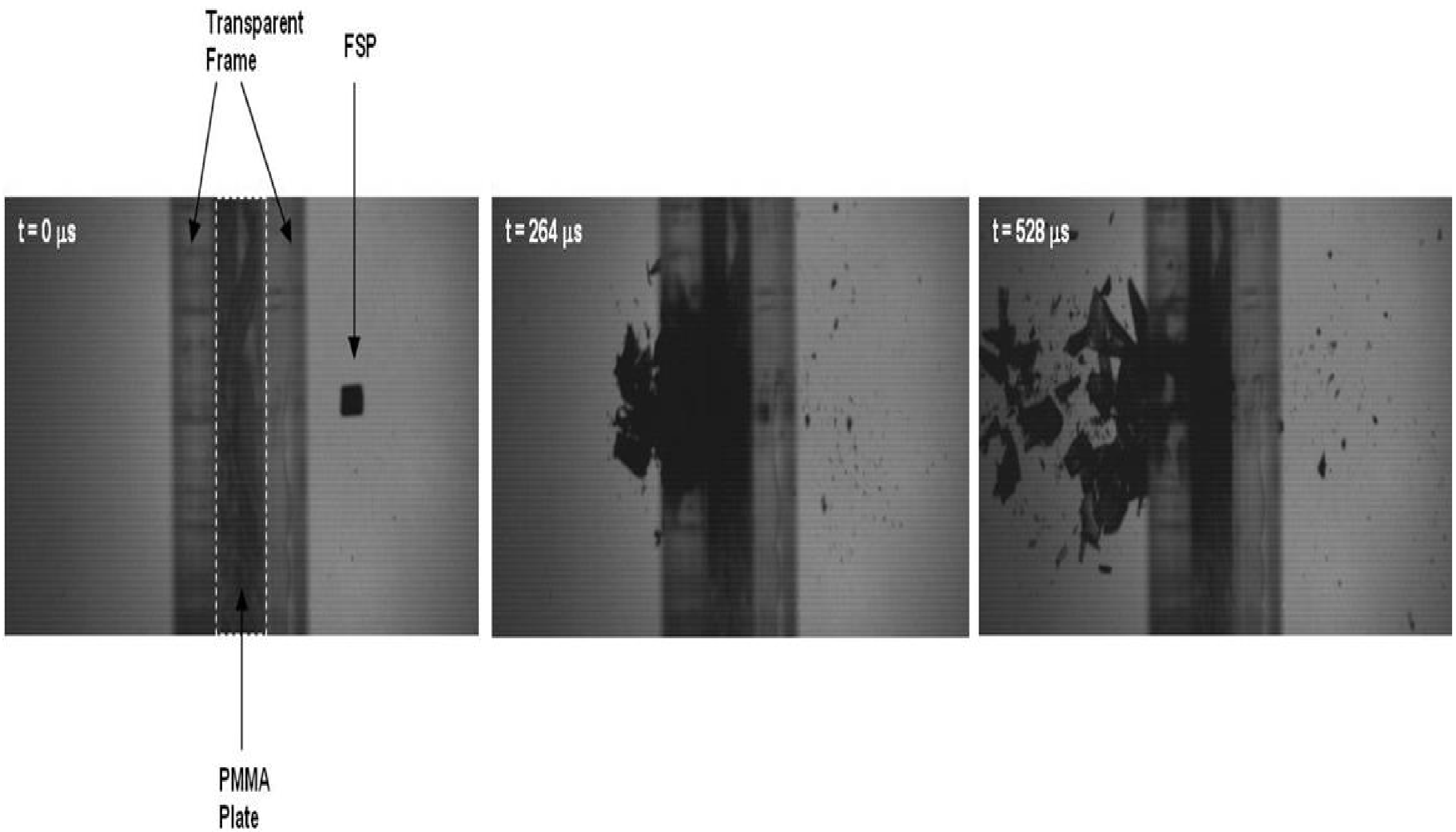
rimental Details-cont.

- The impact on the PMMA target was recorded by a Phantom v7, Vision Research, high-speed camera aiming at 90º to the path of the FSP.
- The targeting area was illuminated by backlighting using a high intensity halogen lamp and a diffuser was used to spread out the light intensity.



High-speed camera setup

Impact Penetration through a PMMA Plate



merical Simulations

Å The numerical modeling was carried out by using the nonlinear analysis commercial software ANSYS/AUTODYN using

- ï 3D axisymmetric models and smooth particle hydrodynamics (SPH) solver
- ï The particle size used for SPH solver was 0.5-mm

Å The dimensions of the model were equal to the dimensions of the actual size target

Å Results were obtained by simulating projectiles impacting the targets at the experimental V50 velocities of

- ï 350 m/s for the 11.84-mm thick targets and
- ï 210 m/s for the 5.92-mm thick target, respectively.

rial Models and Simulation Validation

Å **Steel** was modeled using

ï shock EOS

ï JC strength model.

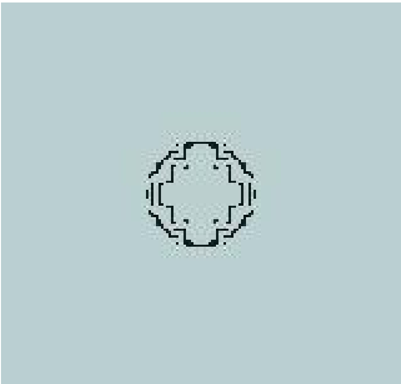
Å **PMMA** was modeled using

ï shock EOS

ï von Mises strength model

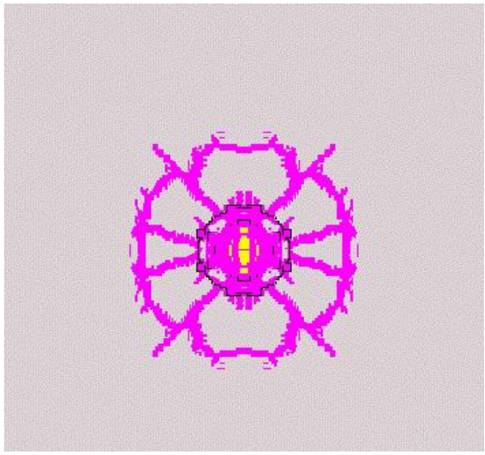
ï principle stress failure criterion with crack softening criterion

Å PMMA Material Model in the Autodyn Library has No Strength and No Failure Criterion.



Simulated Impact before material models modification, .22-cal FSP @350m/s

Actual impact

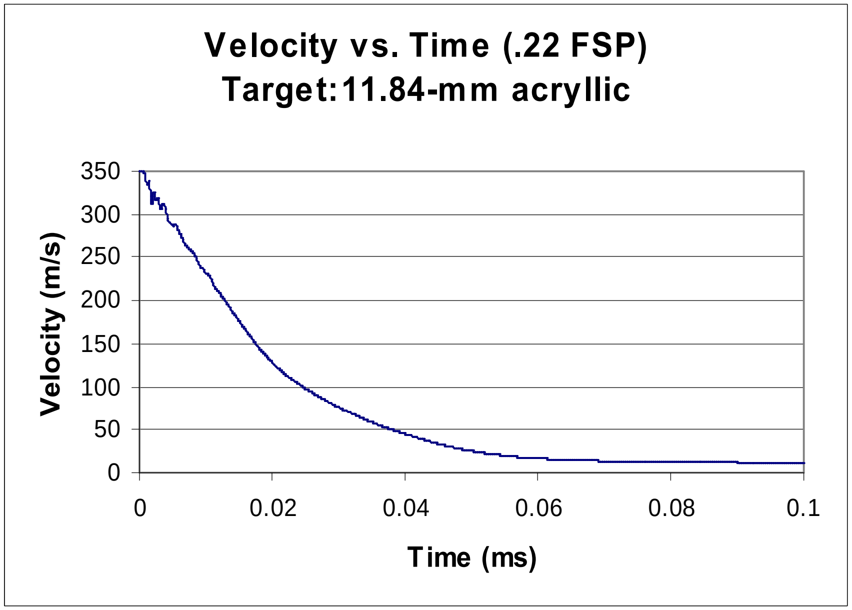


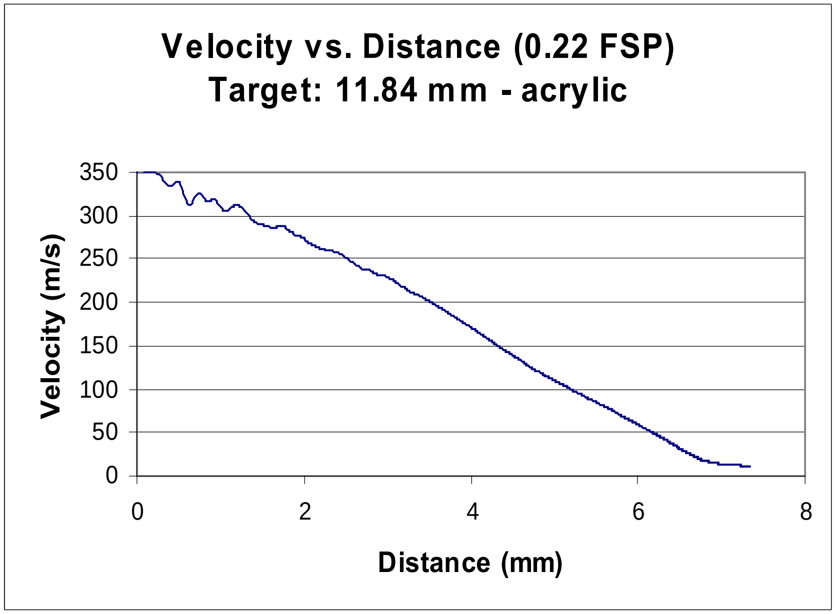
Simulated impact

Actual and simulated target were impacted by .22-cal FSP @ 350 m/s

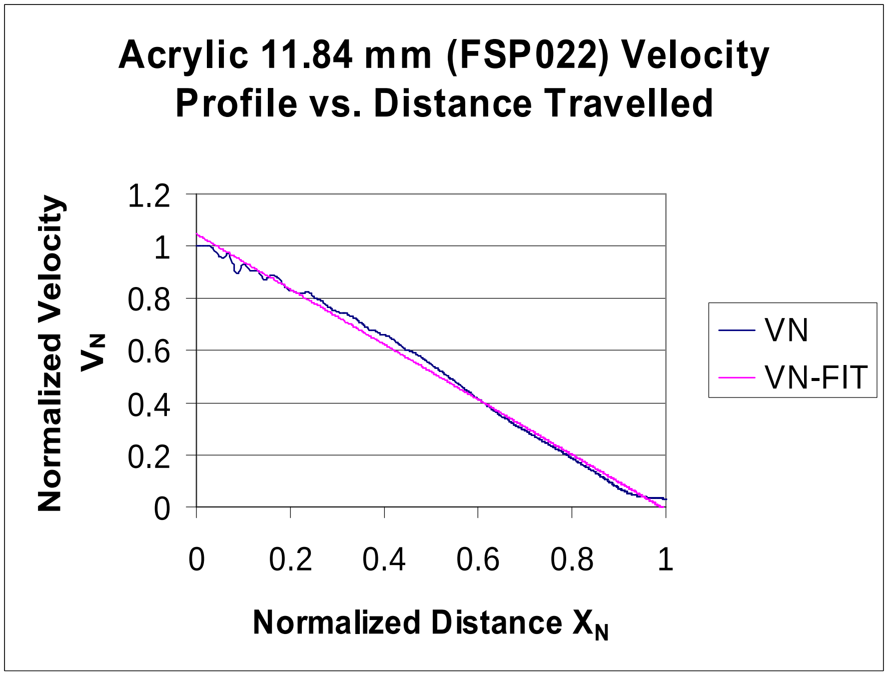
Simulation Results

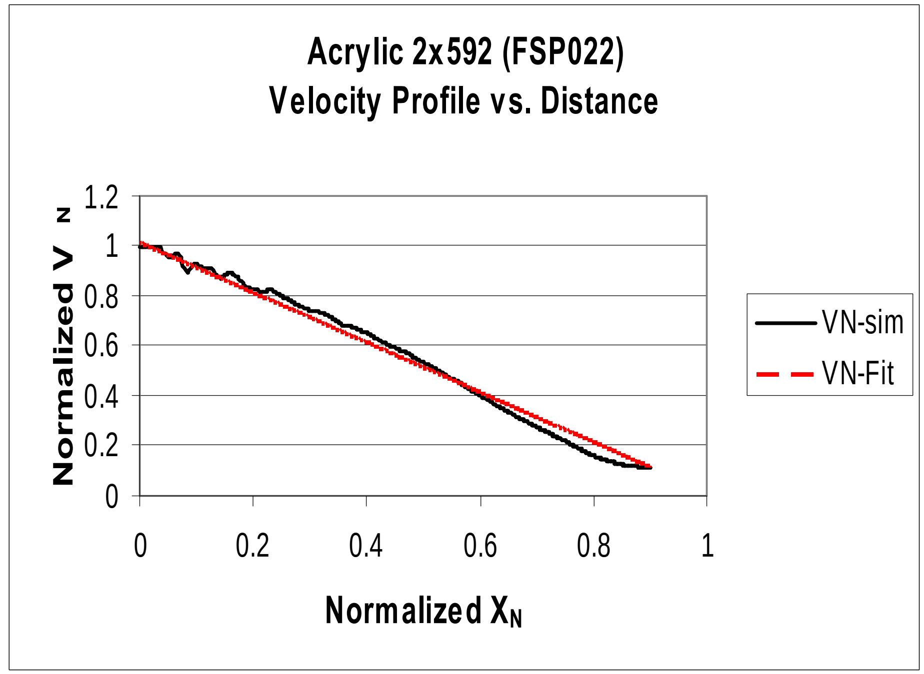
- All simulated exit velocities were within a few meters from the experimental exit velocities
- The analytical expression of the velocity profiles of all impacts was determined by using the LINEST statistical function of the Microsoft Excel





egression Analysis





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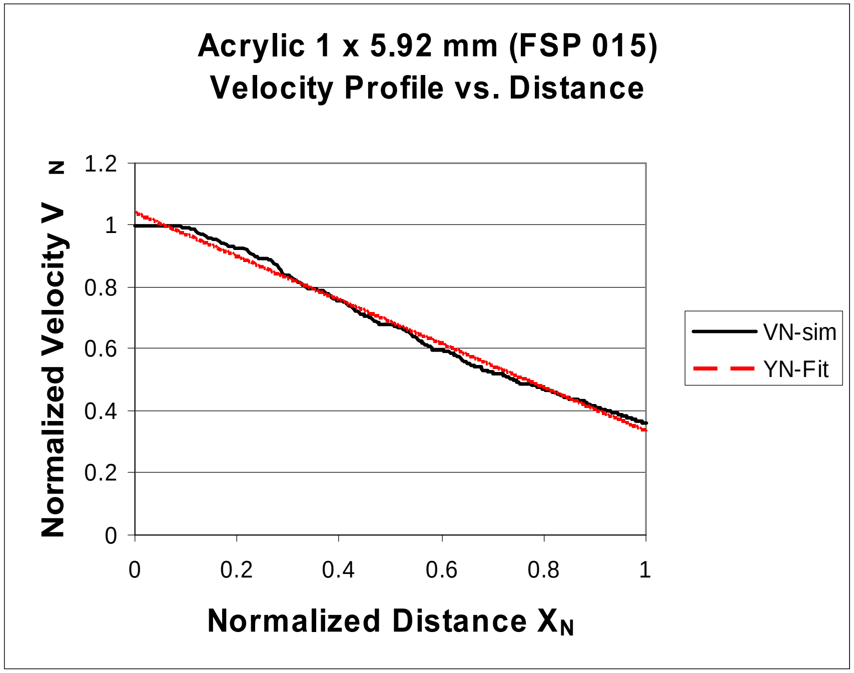
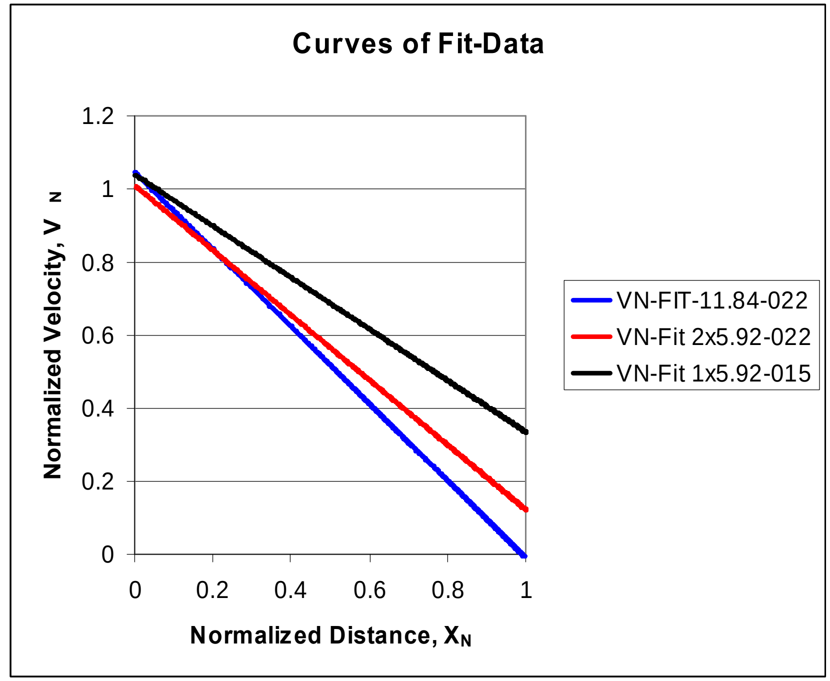




…TIONS OF THE BEST-FIT CURVE …F ALL SIMULATED IMPACTS

Target	Projectile	Velocity	Equation
1x11.84-mm	.22-cal FSP	350 m/s	$V/V_{MAX} = 1.046 - 1.056X_N$
2x5.92-mm (Laminated)	.22-cal FSP	350 m/s	$V/V_{MAX} = 1.010 - 0.888X_N$
1x5.92-mm	.15-cal FSP	210 m/s	$V/V_{MAX} = 1.039 - 0.7045X_N$

V = Instantaneous Projectile Velocity

V_{MAX} = Initial Impact Velocity

CONCLUSIONS

- The current paper has demonstrated the powerful use of computational modeling to produce analytical expressions for the prediction of the energy absorption by an acrylic target, which is impacted by various size FSPs.
- The results of the current study verified, the already known experimentally, that the resistance of an acrylic target to impact by FSP projectiles is affected by the
  - Size of the FSP
  - Impact velocity
  - Target architecture.
- The experimental cracking pattern and the exit velocity of 0.22-cal and 0.15-cal FSPs through monolithic and laminated without intermediate adhesive layer PMMA targets were successfully substantiated by our modified existing strength and failure models of PMMA
  - The PMMA material model was modified by introducing a von-Mises strength model
  - a principal tensile strength criterion using published parameters

Conclusions

Å The equations of the velocity profiles of the various cal FSPs traveling through the PMMA target were produced by regression analysis of the simulated velocity profile using the existing Microsoft Excel software

Å An effort was made to produce an energy loss equation which is not only a mathematical expression, i.e. polynomial equation, but to be related to the physical parameters of the impact, such as impact velocity

Å The **ideal equation** of the energy absorption profile is expected to be

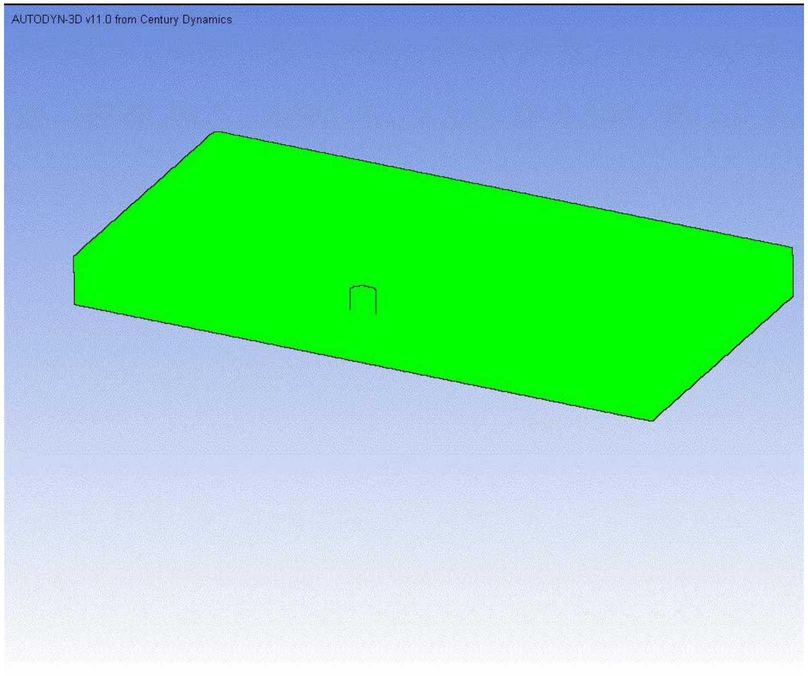
$$(V/V_{MAX})^2 = [1 – (slope)*(X/X_{MAX})]^2$$

Where: V is the projectile instantaneous velocity and X distance travelled by the projectile within the PMMA target

Å Future studies will attempt to
- ï Connect the slope of the equation to the FSP mass and target architecture
- ï Improve the prediction of the failure of the PMMA by simulation for various loading rates of PMMA and laminate geometries
- ï Produce analytical energy absorption expression for a laminate target with more PMMA layers with and without adhesive layer between them.

MOVIES

1 X 11.84-mm PMMA



2 X 5.92-mm PMMA