Using an Experimental Integrated Framework for Soft Armor Design

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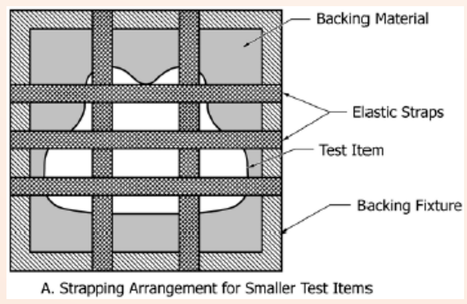
Objective and Motivation

- Design of soft armor based on trial-and error process at present with no insight on mechanics of armor
- Ballistic experiments are expensive and cumbersome
- Need of a systematic and cost-effective design process

Experiment

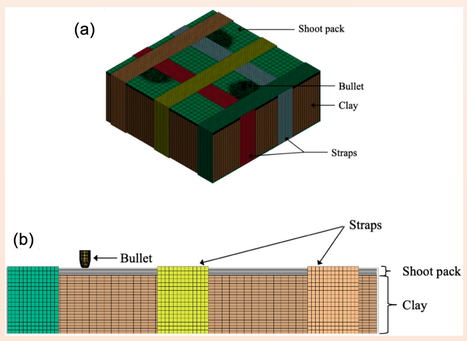
- Soft armor made of SpectraShield©SA-5128 tested
- 3 separate shots of 44 Magnum handgun fired
- Experiment carried out as per NIJ standard against threat level-III A
- All shots stopped by the armor



Schematic of test setup as per NIJ standard 0101.06 [1]

FE Model

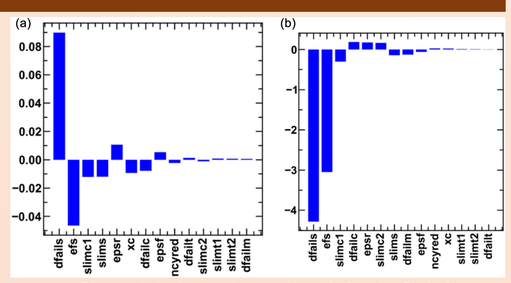
- Four different finite element models developed using LS-DYNA
- Model consisted of four separate parts – backing clay, shoot-pack, elastic straps and the bullet
- Around 70 material parameters were calibrated
- Model is validated against experiment using three metrics – back-face signature (BFS), bullet mushrooming and damage (number of penetrated layers



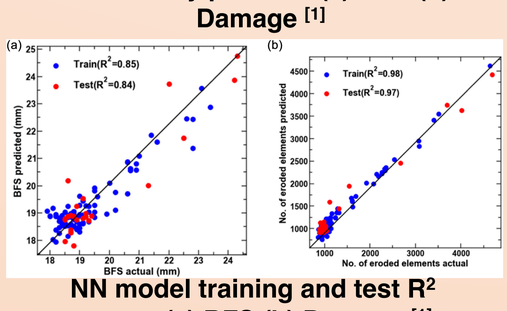
Geometric assembly of finite element model (a) Isometric view (b) Front view [1]

Machine learning

- Sensitivity checked against both BFS and damage
- Parameters governing shear failure and fiber behavior were the most sensitive
- A total of 111 sampling points used as input to the machine learning model
- Six most sensitive material parameters used as independent input features and back-face signature and damage used as output
- Trained neural network model is used to determine the optimum values of material parameters for the model using Bayesian algorithm



Sensitivity plots for (a) BFS (b) Damage [1]

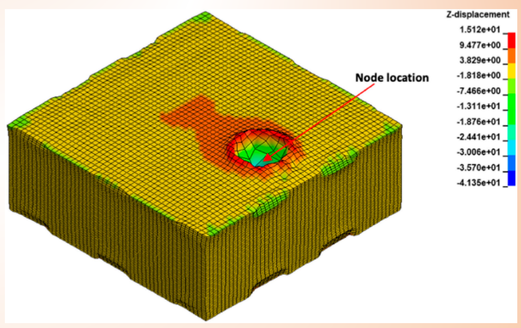


NN model training and test R^2 scores (a) BFS (b) Damage [1]

Results

Back-face signature

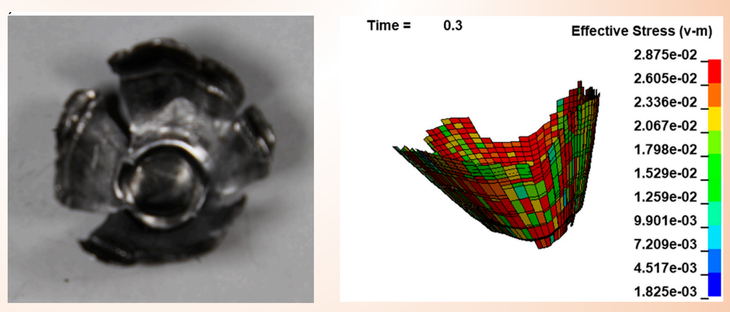
- Experimental value = 40.4 ± 0.99 mm
- Numerical model value = 41.3 mm



Displacement in the Z direction (BFS) [1]

Bullet mushrooming

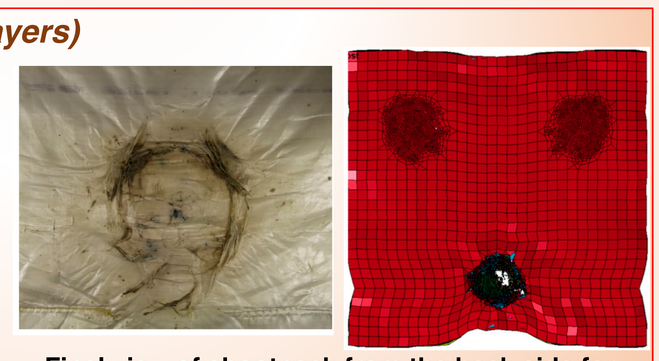
- Residual bullet shape similar to the experiment



Mushroomed bullet in experiment and simulation [1]

Damage (number of penetrated layers)

- Experimental value = 11 layers
- Numerical model value = 12 layers



Final view of shootpack from the back side for experiment and simulation [1]

Source	*Bullet velocity (m/s)*	*BFS (mm)*	*No. of penetrated layers*	*No. of damaged layers in contact with clay*
Test: Shot 1	439.5	41.1	11	2
Simulation: Shot 1	439.5	41.0	12	2
Test: Shot 2	442.3	39.7	11	2
Simulation: Shot 2	442.3	37.8	12	2

Summary of results [1]

Conclusion

- A reliable predictive model for the analysis and design of soft armor is developed using a combination of experiment, machine learning and finite element method.
- Machine learning is used as a cost effective and computationally efficient tool to optimize material parameters.
- The model predicts both BFS and number of penetrated layers with reasonable accuracy.

References

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Acknowledgement

The authors thank Dr Ashok Bhatnagar, Honeywell Fellow, for providing the ballistic test data.