

# Simplified simulation of impact bullet - stratified pack for restraining ballistic tests

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**Abstract.** This paper presents a macro FEM isothermal model for simulating the impact of a 9 mm FMJ bullet on a stratified packs in order to restrain the preliminary tests for actual stratified packs made of layers of Twaron LFT SB1plus (Teijin), taking into account the friction between layers and between bullet and layers, in order to obtain the number of layers that arrest the bullet. The layers were considered as an orthotropic material, with maximum equivalent plastic strain of 0.06. The materials are modeled as bilinear isotropic with hardening. The analyzed parameter to validate the model was the number of broken layers. The average value of back face signature for a 12 layer pack was of 19.44 mm recommending it for protection level of II and IIA (NIJ Standard-0101.06-2008).

## 1 Simulation results

### 1.1 The model

Today, woven or multi-directional fabrics, made of fibers with high impact resistance [1, 2, 3], are used for individual protection armors [4, 5, 6]. Reports on ballistic impact simulation are published, from micro-scale [7, 8] to macro one [9-14], including simplifying hypotheses as considering a rigid projectile [15].

The aim of this paper is to run a simplified simulation of the impact bullet - stratified pack for restraining one or more parameters involved in the pack testing.

The isothermal model has 14 solid bodies: 12 identical layers considered a group of bodies (with the option *multiple materials*), overlapped and rigidly fixed on their contour, and 2 bodies for the bullet (also *multiple materials*) with bonded connections (Table 1, Figure 1). The analysis is of structural type and solved with Lagrangean method, in Explicit Dynamics, using AutoDyn [16, 17, 18]. One layer dimensions are  $6 \cdot 10^{-2}$  m x  $6 \cdot 10^{-2}$  m x  $0.6 \cdot 10^{-4}$  m. As the impact direction is the same to the symmetry axes of the model, the simulation is run for a quarter. The contact among bodies take into account the friction [19]: the friction coefficient between layers is 0.4, characteristic for sliding polyethylene against itself and the friction coefficient between a layer and the bullet jacket is 0.3.

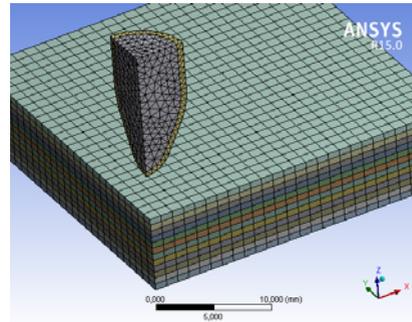
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The meshing (Figure 1) is presented for the pack with 12 layers. The maximum side of an element is  $5 \times 10^{-4}$  m. Initial condition refers to the bullet velocity just before impact (here 400 m/s). Many recent models accepted the rigid clamp on the contour [15], even if for body armor, the pack is simply supported on visco-elastic material. The maximum number of cycles is  $10^7$  and the maximum error for energy was 0.9. Materials are modeled as hardening bilinear isotropic. This simplifying hypothesis could be justified by the arrangement of long aramid fibers, long at four different angles (0, 90, 45, -45) [20]. After consulting the literature [21, 22], the failure criterion was the ultimate plastic strain, set for 0.05.

**Table 1.** Characteristics of the model.

Body	Nodes	Elements
Layer	1250	576
Pack with 12 layers	18816	8748
Bullet (jacket + core)	1432	6289
Bullet jacket	739	2211
Bullet core	996	4078



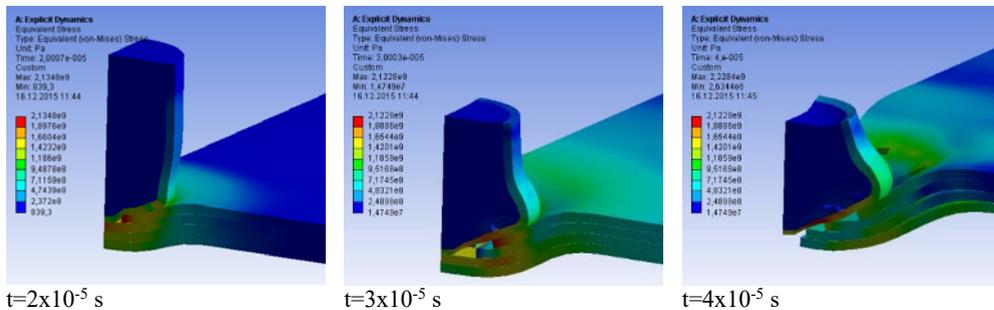
**Fig. 1.** Model meshing, 12 layers.

**Table 2.** Material characteristics used for modeling the impact.

Material	Young, Pa	Poisson ratio	Bulk modulus, Pa	Shear modulus, Pa	Yield limit, Pa	Modulul tangent, Pa
Layer	$7 \times 10^{10}$	0.35	$7.77 \times 10^{10}$	$2.59 \times 10^{10}$	$6.3 \times 10^8$	$1.9 \times 10^{10}$
Copper alloy	$1.1 \times 10^{11}$	0.34	$1.14 \times 10^{11}$	$4.10 \times 10^{10}$	$2.8 \times 10^8$	$1.15 \times 10^9$
Plumb	$1.6 \times 10^{10}$	0.3	$4.44 \times 10^{10}$	$5.55 \times 10^9$	$3 \times 10^7$	$1.1 \times 10^8$

**2.2 Results**

Figure 2 presents time steps of the impact for the pack with 4 layers. Simulation was run for  $2 \times 10^{-4}$  s. After  $1 \times 10^{-4}$  s, the first layer is broken and the stress concentration is not exactly under the bullet tip, but in circular sector of the layer edge, situated at approximately 1/4 of the projectile radius.

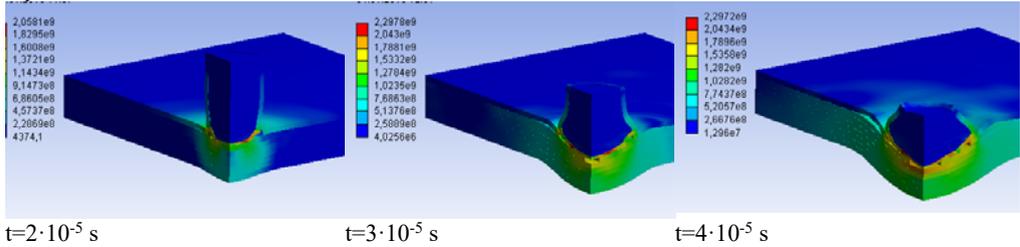


**Fig. 2.** Image of the impact, at different time steps, for a pack made of 4 layers.

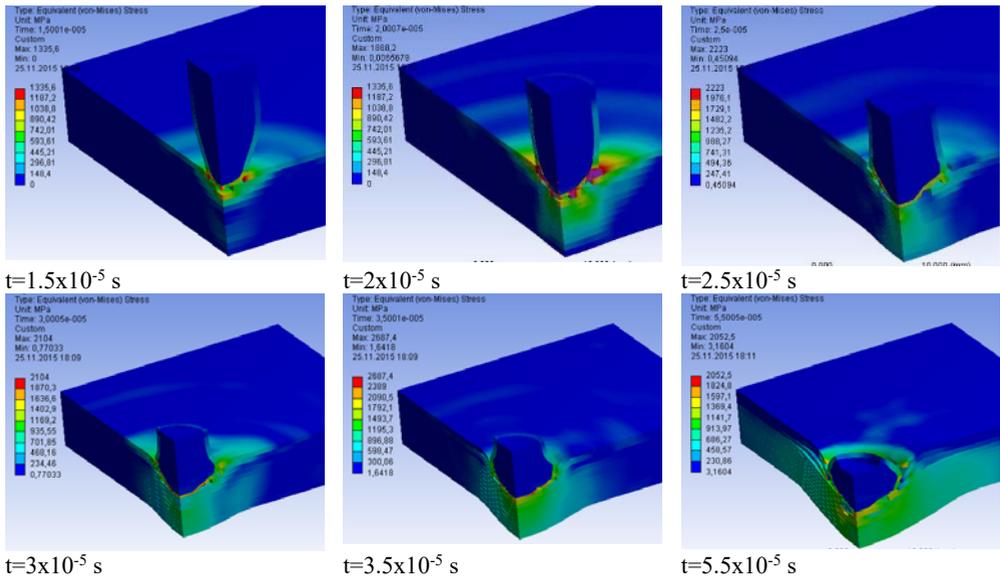
At  $t=2 \cdot 10^{-5}$  s, the maximum stress (2058 MPa) occurs on the bullet jacket and within the first layer, on the impact axes, but also in the volume of the first layer, near the broken ridge that continues to be compressed by the bullet. The first layer has been already broken.

At  $t=3 \cdot 10^{-5}$  s, the second layer is already broken and the first layer is laterally pushed, towards the bullet peripheral zone, producing the jacket thinning (actually, tests revealed the petal broke of the jacket) [23]. The bullet has already had the mushroom shape.

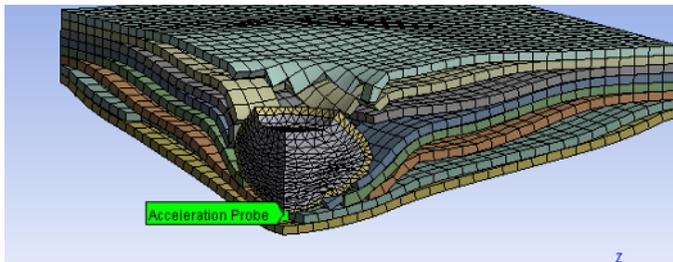
At  $t=4 \cdot 10^{-5}$  s, 4 layers have been already failed. Stress concentrators are noticed on the bullet and near the edges of the broken layers that are still under compression. Layer 3 has high stress value just under the bullet tip (on the model axes). Till  $t=19 \cdot 10^{-4}$  s, no other layer is broken.



**Fig. 3.** Images of the impact of 4 layers pack.



**Fig. 4.** Distribution of von Mises stress for different moments during the impact (12 layers).



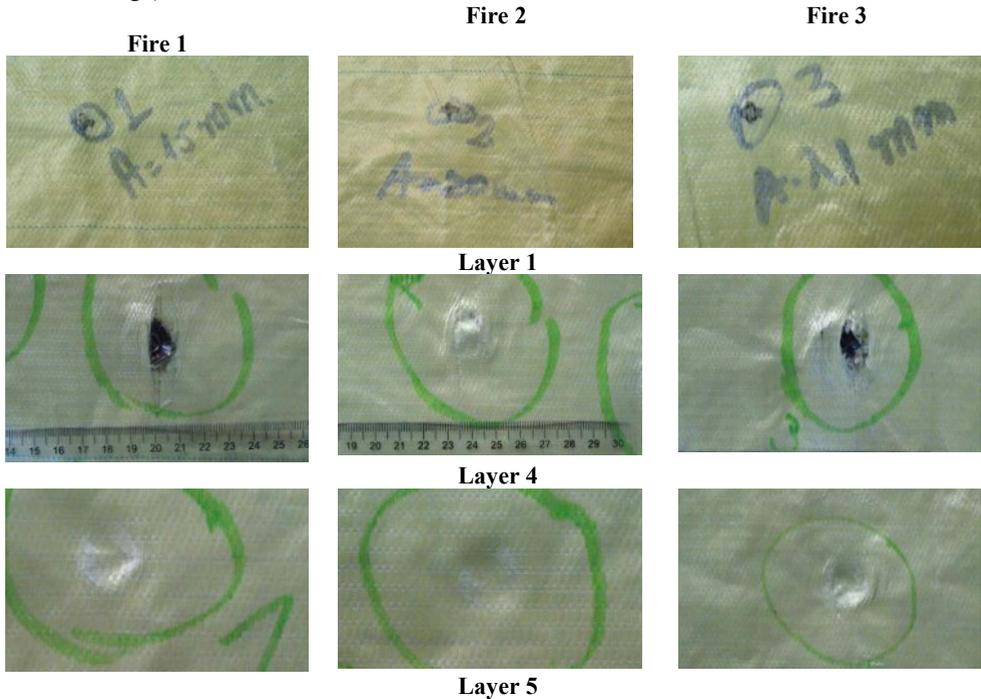
**Fig. 5.** 8 layers pack with 7 broken layers ( $t=10^{-4}$  s).

The simulated deformation of the central point of the pack is 17 mm, close to the measured BFS, for 12 layers packs (see Table 5), even if the actual packs have 500 x 500 (mm).

After shutting, the packs made of 12 layers LFT SB1plus had 4...5 broken layers (Figure 6), similar to the model (Figure 4). For the pack of 8 layers (Figure 5), only the last layers resists. Thus, from running the model, it results a conclusion that tests should begin with packs with 8 or more layers in order not to have total penetration.

### 3 Experimental work

These tests were done taking into account the American standard NIJ 0101.04/2004 [24, 25]: the projectile was a bullet of 9 mm FMJ, initial velocity being measured in the range of 400-420 m/s, and the target was fixed at 3 m. Fires were done in the laboratory of CCSACBRNE, by specialized personnel. The impact velocity was measured with the help of a chronograph Oehler model 43. Other devices included: rigid support for ballistic barrel; a ballistic barrel for bullets of 9 mm FMJ; box for the ballistic clay 610 x 610 x 140 ± 2 (mm); firing table with compensated kick [26]. Test conditions were: 19...23 ± 5°C; relative humidity: 50 - 70%; atmospheric pressure: 760...764 ± 1 mmHg. The clay grade was Roma Plastilina no. 1. The backface signature (BFS) was measured with a depth calipers, having the accuracy of ±0.1 mm. After each measurement, the calipers were cleaned for avoiding eventually adhered clay on the active measuring element. Actual layers were fixed with the help of a sewing line (200 mm on two opposite sides, at 40 mm from the edge).



**Fig. 6.** Frontal view of a sample made of LFT SB1plus [23].

Figure 7 presents the values of backface signature (BFS) for the tested packs. The bold line for 44 mm is the accepted limit according to [24]. The values suggest a further decrease

of the layer number without overpassing this limit, but tests are necessary to confirm this it. The average value for BFS,  $Y_{average}$ , for a number of fire  $N=18$ , is

$$Y_{average}=(1/N) \cdot \text{SUM}(Y_i)=19.444 \text{ mm} \tag{1}$$

$Y_i$  being the value of each BFS,  $i=1...N$  [23]. The results recommend the packs made of 12 layers of LFT SB1plus for a protection level II and IIA. The standard deviation is  $s=4.6554$ .

The upper limit of tolerance,  $Y_u$  [24], for packs made of 12 layers of LFT SB1plus is:

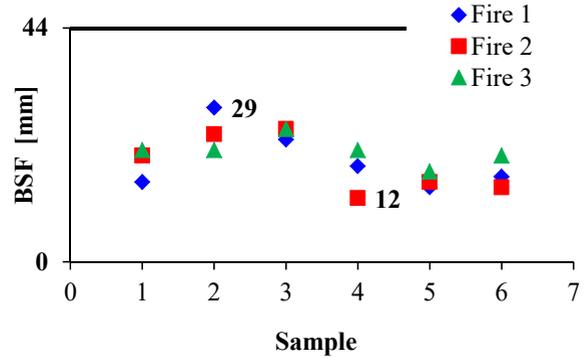
$$Y_u=Y_{average}+K_1 \cdot s=25.9354 \text{ mm} \tag{2}$$

and this value is much less than the permissible one of 44 mm.

**Table 5.** BFS for the packs made of LFT SB1plus layers.

Number of layers/ test number	Fire		
	1	2	3
	BSF [mm]		
12/1	15	20	21
12/18	29	24	21
12/12	23	25	25
12/19	18	12	21
12/13	14	15	17
12/9	16	14	20
8/8	26	TP	TP
8/9	21	TP	TP
8/6	30	33	31

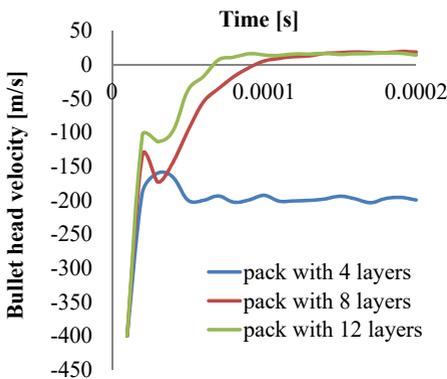
TP - total penetration



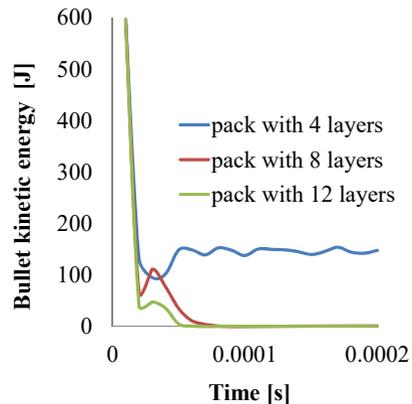
**Fig. 7.** Measured BFS for the packs made of LFT SB1plus layers.

### 4 Conclusions

The simulation pointed out the total penetration for the pack with 4 layers and 7 broken layers in the pack with 8 layers; the pack with 12 layers has only 4 broken ones (Figure 8). Analyzing the evolution of the velocity of the bullet head (Figure 8) and the kinematic energy of the bullet (Figure 9), one may notice the difference between total and partial penetration.



**Fig. 8.** Velocity of the bullet top.



**Fig. 9.** Bullet kinetic energy during simulation.

Thus, the model was validated as for the pack made of 8 layers, there were obtained total penetration for more than half of the fires, but there were bullets arrested between the

8th and 7th layers. But such a risk is not acceptable and tests were done for 12 layers of LFT SB1plus.

The presented simulation on ballistic packs for individual armor with 12 layers, even if it was simplified, estimated the failure of 5 layers, and experiments validate this. Thus, a simulation at macro level may be useful in a rough estimation of the thickness (or number of layers) of the pack. Obviously, the simplifying hypotheses, the material properties and the conditions during simulation (isothermal and with friction) have to have realistic values and the results may shorten the range of some parameters, here the number of layers supposed to resist to a certain threat.

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