Numerical Simulation of a Ballistic Impact on Tensylon® UHMWPE Laminates Using the Plastic Kinematic Model in LS-Dyna®

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***Abstract*—Based on experimental results, the numerical simulation of a ballistic impact between a Ultra-High Molecular Weight Polyethylene (UHMWPE) laminate panel and a 7.62×39 lead core bullet is performed. The aim of the paper is to demonstrate that a simple constitutive model, such as the plastic kinematic model available in LS-Dyna® version R7.0.0, can be used to accurately describe real ballistic impact events with UHMWPE laminate targets, which are normally simulated using orthotropic material models. Two representations of the UHMWPE laminate panel are proposed: a version constituted by a number of identical layers, treated individually as isentropic solids with the possibility of detaching from each other (in order to simulate delamination), and a version containing additional layers between the main UHMWPE layers, having the role of acting, on one hand, as an interface which plays the main role in delamination phenomenon and, on the other hand, to introduce a softer component by imitating the behavior of a resin. Having clearly advantages over the simple non-adhesive version, the adhesive version proposed within this paper had a less accurate performance than the simple version.**

***Index Terms*—ballistic impact, constitutive model, numerical simulation, plastic kinematic, Tensylon®, UHMWPE.**

I. Highlights on the Behavior of UHMWPE Laminates at Ballistic Impact

Ultra-high molecular weight polyethylene (UHMWPE) laminates are acknowledged materials which stand at the production base of numerous ballistic protection products, world widely known as lightweight solutions [1].

Over the past thirty years, a number of authors highlighted through experimental studies in the field and at laboratory scale the particular material properties which confer the unique ballistic performance of UHMWPE composites. Frissen [2], for instance, showed that the main characteristics of these materials relevant to the recalled aspect are: the high Young modulus at high strain rates, the low density and the relatively high strain to failure. These parameters interact in the following way: the low density and the high modulus determine high impact wave speeds within the material, both longitudinal and transversal. A high longitudinal wave speed translates through a high quantity of energy absorption, by engaging a larger material area. On the other hand, the bigger the wave speed, the less deformation will the fibres/filaments withstand, at impact velocities exceeding a certain value. This means that the composite material (also called laminate), more precisely, its Young and shear moduli, are strongly dependent on the strain rate at high impact velocities, because of the visco-elastic character of the filaments and the matrix.

However, this aspect is nearly impossible to implement in numerical simulations, especially in the context where there are yet no adequate means, to the authors' knowledge, of measuring and quantifying this dependence during the ballistic impact process.

II. Experimental Ballistic Impact Procedure and Results

The experimental trials that are at the base of the numerical simulations reported in this article were thoroughly described and analyzed in a previous article [3]. A number of different Tensylon® based panel configurations for individual protection, with and without thin (2-3 mm thick) steel sheets used as back and/or front supplementary protections, having Tensylon® UHMWPE laminates (22.5 mm thick) as the main component, were tested against 7.62×39 mm full metal jacket, lead core projectile. Although the bullet is not stated to be used in the international standards [4-6], it is a well known fact that this caliber is frequently used in specific missions, especially in peace maintaining missions on the east fronts, where Kalashnikov represents a common weapon both for the combatants, as well as for terrorists, being easily accessible to a large category of people.

For the present study, only the bare UHMWPE panel configuration was considered, as a starting point for analyzing further different configurations in combination with other types of materials (metals, alloys, ceramics, etc.). The next paragraphs resume the experimental procedure and the results obtained for this particular trial.

Due to its limited dimensions of 25×30 cm, the ballistic impact on the Tensylon® panel was restrained to a number of two strikes. The panel was subsequently sectioned through the middle of the impact hole via waterjet cutting, making possible the post-mortem analysis of the inside phenomena through post-processing of its transversal photography. One of the holes was also filled, prior to waterjet sectioning, with clear resin, in order to maintain post-mortem placement of the cavity damaged inside (delaminated layers, metallic fragments, ruptured filaments, etc.).

Table I encapsulates the measurements of the main deformations based on the cross sections photographs. The considered dimensions are illustrated in Figure 1. Figures 2 and 3 illustrate the two impact holes cross-sections of the same panel sample. The measuring errors couldn't be

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quantified, but a percent of 2% is estimated, according to the differences between the measurements performed on the same impact, only on different sides of the cross section.

TABLE I. MEASUREMENTS PERFORMED ON THE CROSS SECTIONS PHOTOGRAPHS (FIGURES 2 AND 3), USING THE ANALYZING DIGITAL IMAGES (ADI) SOFTWARE

	Side	Exterior deflection [mm]	Interior deflection [mm]	Diameter of the bullet trace [mm]	Penetration [%]	Dimension of the unpenetrated portion [mm]		
						Normal* (Uncompressed)	Final	%
Impact 1	1	5.1	14.54	7.2	32.2	15.4	14.8	3.9
	2	4.7	16.7	7	32.8	14.93	14.9	0.2
Impact 2	1	5.2	12.26	6.2	32.8	15.2	14	7.9
	2	4	12.9	6.7	32.3	15.6	14.4	7.7

**Calculated by considering the original thickness of the sample (before the impact) of 22.5 cm*

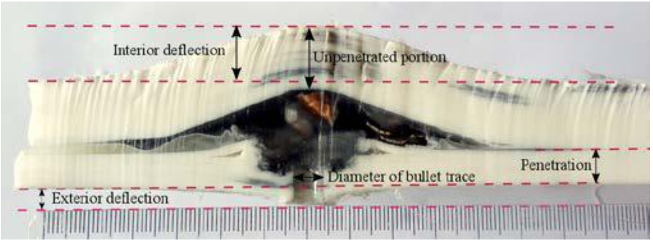

Figure 1. Significance of the measured dimensions in Table I

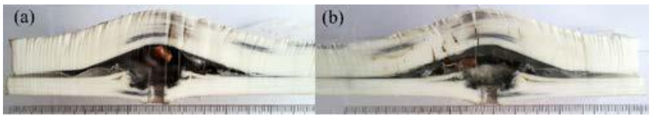

Figure 2. Cross-section through the no. 1 impact (a) side 1 and (b) side 2

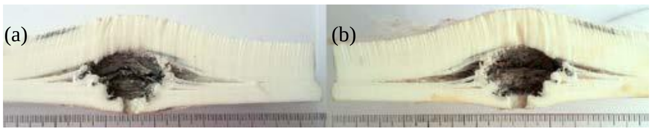

Figure 3. Cross section through the no. 2 impact (a) side 1 and (b) side 2

The main post-mortem aspects observed and considered for the simulation study were the following:

1. The first observable consequence of a ballistic impact into a UHMWPE panel is a significant back face deformation (opposed to the impact point). In the considered case, it had an approximate diameter of 10 *cm* in diameter, the deflection being concentrated to the middle of the impact. The back face deformation is associated to the back face signature, also known as the blunt trauma, which is extremely important in establishing the ballistic performance of a protection structure. The maximum admitted is 44 *mm* [5], therefore the considered panel was within the imposed parameters.
2. The bullet penetrated approximately a third of the total panel thickness (~33%). The penetration stage is also described in the literature [2] as "punching", having the meaning of "to perforate".
3. The behavior of the filaments and layers are considered individually in order to establish the "penetration mechanisms", as defined in the literature, having the meaning of "mechanisms for stopping the projectile". The most important mechanism, besides the "punching", which is likely to be represented in a simulation is delamination. Other mechanisms may be: stretching and bulging (of the filaments after rupture). All these mechanisms experimentally observed are illustrated in Figure 4.

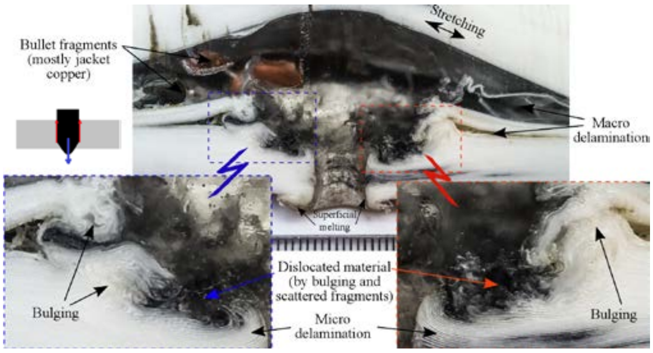

Figure 4. The penetration mechanisms in the Tensylon® panel

III. THE NUMERICAL SIMULATION OF THE BALLISTIC IMPACT PHENOMENON

The modeling of the ballistic impact event was done using LS-DYNA R7.0.0, a specialized software for modeling the non-linear transient phenomena. Due to the radials concentrated effect of the bullet on the UHMWPE panel, we were able to downsize the normally 25×30 *cm* target to a Ø10 *cm* cylinder. With the projectile being concentric as well, we were able to use an axysymmetric representation of the bodies, thus reducing the number of elements and the overall resolving time. Therefore, axysymmetric volume weighted solid elements, type SHELL 15, were used. In this case, the *y* axis is the axis of symmetry and the *x* axis corresponds to the radial direction.

The constitutive model for all the solids involved in the impact event was chosen to be the plastic kinematic model, counting on both the simplicity of the model and its capacity to accurately reproduce real dynamic behavior of the materials.

A. *Modeling of the projectile*

The dimensions of the lead core 7.62×39 *mm* FMJ projectile were approximated based on its cross-section photography, knowing the exterior dimensions (Figure 5). The projectile was successively represented in Solidworks, then it was imported in ICEM CFD, where the model was meshed, accounting for its shape. Thus, the smallest element dimensions are 0.02×0.03 *mm*, whereas the biggest are 0.1×0.18 *mm*. Other data on the construction characteristics of the model are given in Table II.

It is known from the literature that, in order to exclusively analyze the answer of the target to a ballistic impact, it is preferable to use undeformable projectiles; for the experiments considered, the answer of the deformable projectile core was previously calibrated in our laboratory, such that its behavior would not alter the behavior of the composite material targeted in this series of numerical investigations.

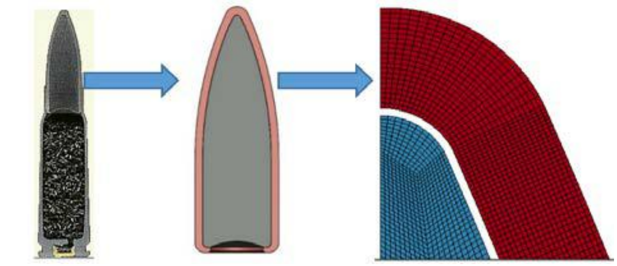

Figure 5. Graphical representation of the lead core 7.62×39 mm projectile

TABLE II. CONSTRUCTION CHARACTERISTICS OF 7.62×39 MM LEAD CORED PROJECTILE, MODELED IN THE PRE-PROCESSOR ICEM CFD

Part	Number of elements	Number of nodes	Initial conditions and constraints
Jacket	5600	5901	- Initial velocity 700 m/s - Displacement on OY
Core	4900	5161	
Total	10500	11062	

The interaction between the bodies was realized with the card *CONTACT_2D_AUTOMATIC_SURFACE_TO_SURFACE_ID, using different adjustments of the static friction coefficient (FS) and the dynamic friction coefficient (FD). Thus, for the contact between the parts of the same body (projectile, panel), both FS and FD were set to 0, and for the interaction between the components of the panel and the bullet, FS = 0.7 and FD = 0.6. However, the dynamic coefficient would only work when accompanied by a non-zero value of the exponential decay coefficient (DC) – which was chosen equal to 0.02. The material properties of the two components of the projectile, as implemented in the plastic kinematic material model, are encapsulated in Table III.

In order to account for the deformation of the projectile core, but also to avoid the apparition of the errors caused by the possible negative volume elements, an erosion law was defined, using the card *MAT_ADD_EROSION – the variable shear strain at failure (γ_{max}) was set to the value of 2.8 *MPa*.

TABLE III. THE PLASTIC KINEMATIC MATERIAL MODEL PROPERTIES USED AS INPUT FOR MODELING THE JACKET AND CORE MATERIALS OF THE PROJECTILE

Material considered	The plastic kinematic model parameters*									
	RO [tons/mm^3]	E [MPa]	PR	SIGY [MPa]	ETAN [MPa]	BETA	SRC [s-1]	SRP	FS	VP
Jacket (Copper)	8.5 E-9	1 E+5	0.33	120	100	0	1 E+5	1	0.8	1
Core (lead)	1.12 E-8	1.1 E+5	0.37	20	50	1 E+9	1 E+9	1	0	1

** Symbols: RO = mass density, E = Young's Modulus; PR = Poisson ratio; SIGY = Yield stress; ETAN = tangent modulus, BETA = hardening parameter, SRC = strain rate parameter, C, for Cowper Symonds strain rate model (if zero, rate effects are not considered), FS - Effective plastic strain for eroding elements, VP - Formulation for rate effects [7].*

The initial velocity of the projectile was set to 700 *m/s* using the card *INITIAL_VELOCITY_GENERATION.

B. Modeling of the target

1) Considerations on the representation

Frissen [2] demonstrated that a Ø20 cm disk is enough to model a ballistic impact with a thick UHMWPE composite panel. Following ballistic tests, he concluded that, from a total of 100 *μs*, the approximate duration of the ballistic phenomena, only the first 20 *μs* are critical for establishing an answer from the material. In case where the impact isn't leading to a total penetration, the velocity of the projectile will reduce by more than 50%. The deformation wave transmitted through the material travels at approximately $5 \cdot 10^3$ *m/s*, which means that in 20 *μs* it will be around 10 cm away from the impact epicenter. Beyond this radius, the material remains "inert", thus the freedom points on the circumference of the disk can be suppressed.

According to our own experimental results, it was confirmed that, indeed, in order to intercept the back face deformation in totality, this Ø10 *cm* disk dimension is enough. The photographs of the cross-section also confirm an approximate 5 *cm* radius of the back face deformation.

The three-dimensional (3D) models have the advantage of being capable to describe the transversal stresses and strains in the immediate vicinity of the impact. However, the ballistic behavior of the composite materials in a non-destructive (partial penetration) analysis is controlled by the propagation of the longitudinal and transversal waves, which can be described by using bi-dimensional (2D) models. In addition, the 2D models are more affordable and easier to interpret. For a facile understanding of the proposed problem, in Figure 6 illustrates a 3D scheme of the axysymmetric, 2D-implemented model.

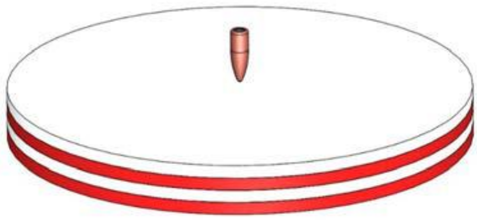

Figure 6. 3D schematization of the problem: the layout of the 7.62×39 mm, lead cored projectile and the Tensylon®-based composite target (the model is proportional, except for the thickness of the criss-cross layers, which are only illustrated to represent the ortotropic character of the material)

The failure limit of the material was set by using an eroding condition, through the card *MAT_ADD_EROSION – the failure is initiated when the maximum principal strain (variable "mxeps") reaches 0.3 (30%). The material characteristics corresponding to UHMWPE are gathered in Table IV.

TABLE IV. THE PLASTIC KINEMATIC MATERIAL MODEL PROPERTIES USED AS INPUT FOR MODELING THE UHMWPE MATERIAL

RO [tons/mm^3]	E [MPa]	PR	SIGY [MPa]	ETAN [MPa]	BETA	SRC [s-1]	SRP	VP
9.62E-10	21330	0.27	320	7040	0	0	1	1

It is acknowledged that, at high strain rates, the Young Modulus is strongly dependent on the strain rate, but also on the previous estates of the materials (characteristic which is evidenced by the hysteresis phenomena on the unloading curve). Thus, it is possible that the elastic modulus of UHMWPE to modify, during the impact, its value with several size orders - for example, from approximately 120 *GPa* (the reported value for one single UHMWPE fibre/filament in traction or compression) to approximately 2 *GPa* (the determined value of the UHMWPE in laminate form, via Hopkinson bars experiments [8]). The variation of this parameter during the simulation running is only possible by implementing a user defined model, and not only does it require more computational resources, but also more time, knowledge and experimental tests to calibrate and implement it.

Therefore, a compromise had to be made. Due to limited time and computational resources reasons, only one version of the UHMWPE parameters set implemented in the simulation is presented, accounting for the following facts:

1. The plastic kinematic model which was previously calibrated to accurately describe some medium strain rate Hopkinson bars experiments on the Tensylon® laminate [8] proved to be insufficient for a ballistic impact event simulation.
2. The chosen plastic kinematic model, having an approximately ten times larger Young modulus than the medium strain rate calibrated version, was previously used in our laboratory to accurately describe ballistic events on Dyneema® laminates, and is also more similar to reported material models in the literature for the simulation of high strain rate events [9].

Two representations of the target were implemented, starting from the pre-preg thickness size (equivalent to two unidirectional tapes), as follows:

1. Model 1 of the sample considers a number of layers equal to the number of pre-pregs contained by the real sample, and each layer constitutes an isotropic solid. Such a representation could be considered, without further established conditions, to be identical to a bulk isotropic solid. Modeling each layer with independent nodes and elements allows, however, visualizing the delamination phenomena specific to laminate materials. Thus, this simulation version becomes a meso-scale approach, which will be referenced in the following paragraphs as the "non-adhesive version".
2. Model 2 considers in addition some softer "adhesive" layers, with specific parameters, which act as an inter-ply "interface" between the UHMWPE pre-preg layers. This model will be referenced as the "adhesive version"

2) *Non-adhesive simulation version*

First of all, in order to facilitate the discretization of the target, the UHMWPE layers were represented by two different bodies, having each half the number of the total pre-pregs layers, off-set to each other by a layer thickness. Next, the discretization was done progressively, in order to obtain finer elements in the impact zone and coarser elements towards the edge of the disk. Thus, the smallest elements (in the vicinity of the axis) were 0.1×0.1 *mm*, and the biggest elements (on the extremities) were 0.1×3.66 *mm*. The thickness of a layer was 0.1 *mm*, and the total thickness of the simulated target resulted in a value of 23 *mm*. In order to intercept the delamination phenomena, the nodes were independent for each of the two bodies, i.e. they were duplicated at the interface between two consecutive layers. Subsequent information about the non-adhesive model is found in Table V.

TABLE V. THE CONSTRUCTION CHARACTERISTICS FOR THE NON-ADHESIVE MODEL

Part	Number of elements	Number of nodes	Observations
Part 1	8625	17480	115 layers
Part 2	8625	17480	115 layers
Total	17250	32958	Duplicated nodes

3) *Adhesive simulation version*

This model is defined by an extra layer of adhesive placed between the polyethylene layers. We assume that, similar to the UHMWPE, the adhesive material also experiences modifications of its characteristics at high strain rates. However, the simple material model chosen would not allow taking this fact into account.

Due to the much smaller thickness of the adhesive layers (compared to the UHMWPE layers), a finer discretization was imposed. Thus, the smallest polyethylene elements (in the vicinity of the axis) were 0.048×0.1 mm, and the biggest (on the extremities) were 0.0936×0.1 mm. The adhesive element dimensions were in the range 0.048×0.015 mm - 0.0936×0.015 mm. The resulted thickness of the sample was 22.87 mm (Figure 7).

Table VI encapsulates the material characteristics for the adhesive, and in Table VII the construction characteristics of the target are presented.

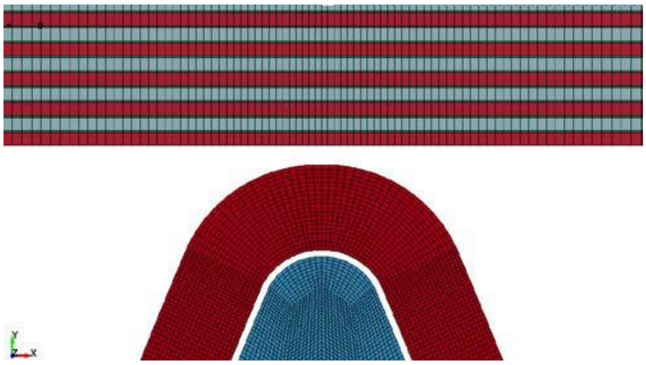

Figure 7. Discretization detail of the assembly, the adhesive version, impact zone

TABLE VI. THE PLASTIC KINEMATIC MATERIAL MODEL PROPERTIES USED AS INPUT FOR MODELING THE ADHESIVE MATERIAL

RO [tons/mm^3]	E [MPa]	PR	SIGY [MPa]	ETAN [MPa]	BETA	SRC [s-1]	SRP	VP
1.2E-9	4000	0.35	100	2000	1	1E+9	1	1

TABLE VII. THE CONSTRUCTION CHARACTERISTICS FOR THE ADHESIVE MODEL

Part	Number of elements	Number of nodes	Observations
Part 1	25000	50200	100 layers
Part 2	24750	49698	99 layers
Adhesive	49500	99396	198 layers
Total	99250	199294	Duplicated nodes

4) *The material answer at ballistic impact loading*

It is indicated in the literature that, under ballistic impact, the projectile's velocity isn't linearly decreasing over a certain amount of time, during which the material is most likely to fail by filament breakage. During the second part of the penetration, the material takes over the rest of the projectile kinetic energy by means of extensive deformation (back face deformation). In case of a deformable projectile, the ballistic performance increases due to the increase of the target-projectile contact surface, which means that higher amount of kinetic energy needs to be absorbed.

The fulfilled experiments which are at the base of the present study [8] can be compared with those conducted by [2], which used deformable fragments with an initial velocity of 700 *m/s* (Figure 8). The report submitted by Frissen highlights that during the first 10 *ms* the projectile's velocity dramatically drops, from 700 *m/s* to about 300 *m/s*. During this time, the compressive force perpendicular to the thickness of the composite material is high, and the contact force as well, which is likely to result in the fast failure of the filaments (layers). After 10 μs, in a sufficiently thick composite plate, the punching process will be stopped following the reduction of the contact forces. In the next 30 μs, the projectile will be slowed down and eventually stopped through the deformation of the unperforated portion of the laminate.

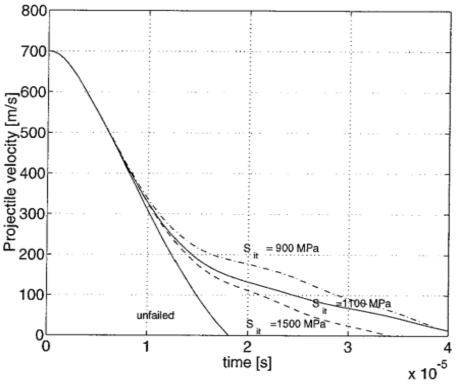

Figure 8. The velocity decrease of the projectile during the impact with an UHMWPE laminate panel [2]

C. The simulation results

The simulation results were analyzed both visually and graphically, as follows. Figures 9 and 10 illustrate graphical representation of the problems evolution. Table VIII encapsulates some measurements of the back face deformation, as it results from analyzing the graphical representation, accompanied by the BFD displacement graph (Figure 11).

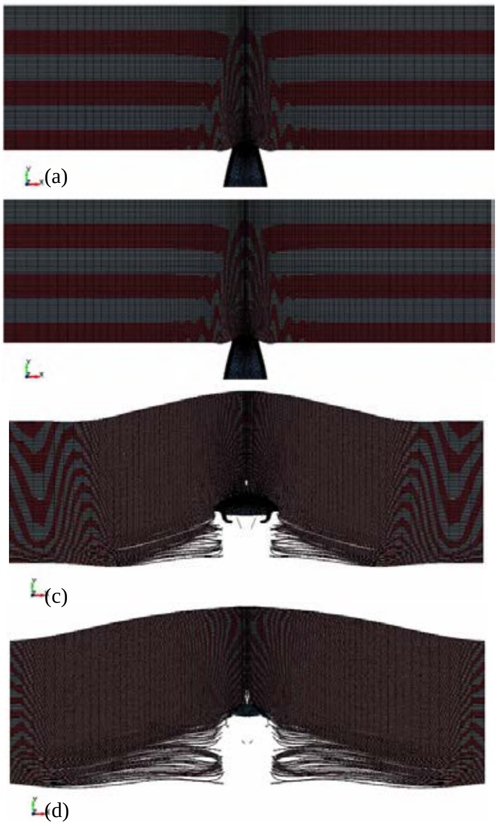

Figure 9. The evolution of the non-adhesive version of the UHMWPE ballistic impact problem – (a) $t = 5\mu s$; (b) $t = 20\mu s$; (c) $t = 45\mu s$; (d) $t = 65\mu s$

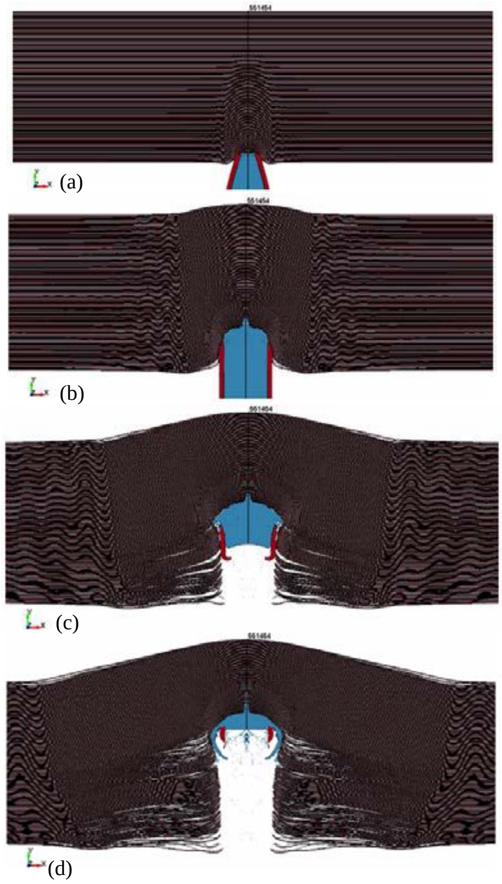

Figure 10. The evolution of the adhesive version of the UHMWPE ballistic impact problem – (a) $t = 5\ \mu s$; (b) $t = 20\ \mu s$; (c) $t = 45\ \mu s$; (d) $t = 65\ \mu s$

TABLE VIII. THE OBTAINED VALUES FOR THE BFD DIMENSIONS – USING *ANALYZING DIGITAL IMAGES* ON THE ABOVE IMAGES (FIGURES 9 AND 10), REFERENCING AS MEASURING UNIT THE OUTSIDE CALIBER OF THE BULLET

Simulation version	Measuring source	The radial dimension of the deformation on the back side of the panel (BFD) [mm]				
		$t = 5\ \mu s$	$t = 20\ \mu s$	$t = 45\ \mu s$	$t = 65\ \mu s$	$t = 75\ \mu s$
Non-adhesive	ADI	-	24.3	51.6	73	-
Adhesive	ADI	-	18.8	41.4	60.3	65.7
		The transversal dimension (on the panel thickness direction) of the back face deformation (BFD) [mm]				
Non-adhesive	ADI	-	2	4.9	5.5	-
	Extracted from the BFD graph		2	5	5.6	-
Adhesive	ADI	-	1.4	3.9	5.9	6.25
	Extracted from the BFD graph		1.6	4.5	6.7	6.9

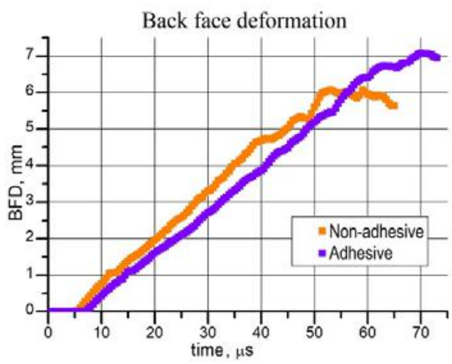

Figure 11. The back face deformation (BFD) evolution; the values represent the OY displacement of a chosen node, situated on the back face of the panel, close to the symmetry axis

On BFD level, it is observed that the measuring performed through the ADI software present some gaps relative to the nodes displacement, especially for the adhesive version. The apparent measurement errors are due to the fact that the delamination of the plate occurs in an expanded volume, the sample thickness rising in the area situated beyond the visible deformation. The difference could also be explained by the rebound of the panel, due to the elastic behavior introduced through the presence of the adhesive. At the same time, it is to be noticed that the maximum deformation is achieved faster in the case of the non-adhesive version than the adhesive version, which is also explained by the use of the adhesive layers - its presence causes an increased number of reverberations, which delay the transmission of the compression wave within the volume of the sample. In relation to the experiment, however, both results are underestimated by approximately 50% (the reference value being approximately ~ 13.5 *mm*, according to Table I – column “internal deflection”). Regarding the radial dimension of the BFD, the results can be appreciated as overestimated, although the adhesive model approaches more the actual value of approximately 50 *mm*, with the 6.25 *mm* measured in ADI.

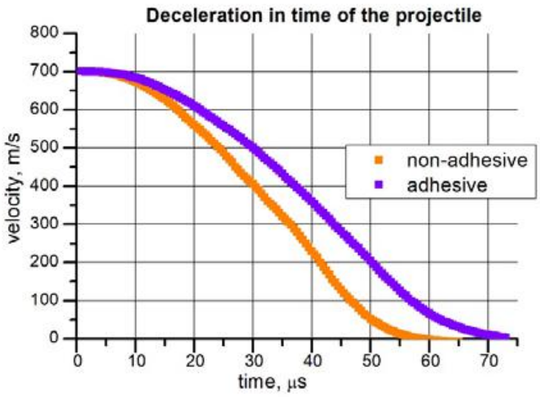

Figure 12. Deceleration of the projectile following the impact with the UHMWPE panel

The deceleration of the projectile (Figure 12) is taking place within an interval of approximately 60-70 μs, range which is in accordance with the usual values reported for ballistic impact events. In the adhesive version, because of the “soft” component, the projectile is decelerating slower, so it destroys a deeper portion of the panel.

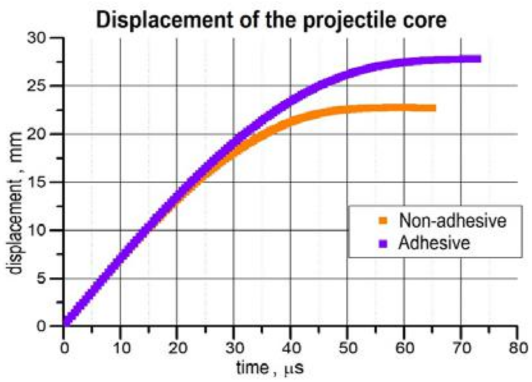

Figure 13. Displacement of the projectile

The projectile displacement chart (Figure 13) shows the size of the inner cavity formed by its passing through the material. For the non-adhesive version of simulation, the cavity dimension is optimal, its 23 *mm* overlapping over the real dimension. In the case of the adhesive version, the 27 *mm* value indicates that the projectile has penetrated more than 30% of the material. In order to determine the exact amount of intact layers and their compression value, we followed the evolution of distance in time between two considered nodes: the first, immediately above the stopped projectile and the second on the back face of the plate. Figure 14 is the variation graph corresponding to this distance.

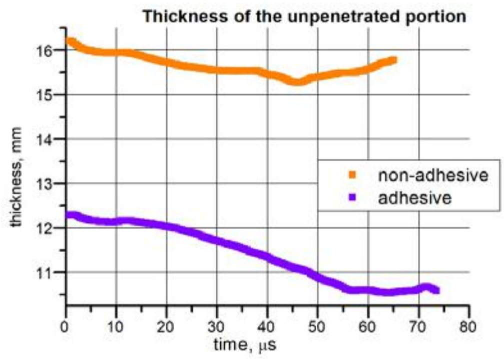

Figure 14. The evolution graph of the unpenetrated portion thickness

In case of the non-adhesive version, the thickness of the non-penetrating part evolves from 16.2 *mm* (representing 70% of the initial thickness of the represented panel, which is ~ 23 *mm*), compressing to a maximum of 15.25 *mm* (5.8% deformation) at $t = 45\,\mu s$, then returns to a value of 15.75 *mm* (2.8% deformation) at time $t = 65\,\mu s$. In case of the adhesive version, the thickness of the non-penetrating part evolves from 12.3 mm (53% of the initial thickness of the plate), compressing to a final value of 10.5 *mm* (14.6% deformation). From these data, we understand that the version that fits best the real phenomenon is the non-adhesive one, with only 30% penetration, compared to 47% penetration in case of the adhesive version.

The deformations and stresses within the sample, at different points on both ends as well as in the panel volume, were analyzed nearby the symmetry axis (in order to remain within the range of maximum stresses and deformations). Stresses were found to be significant in the bullet impact zone, within the elements that were destroyed in the first 15 μs (Figure 15). It is to be noted that, in the case of non-adhesive version, these stresses are about 2 *GPa*, while in the case of adhesive version, they are about two times smaller (around 1 *GPa*). Within the unpenetrated volume of the sample, stresses of approximately 1.5 *GPa* were recorded for the non-adhesive version, respectively 0.8 *GPa* for the adhesive version.

Regarding the strains (Figures 16 and 17), they were also more significant nearby the impact zone (the elements that yielded deformed by up to 30% in both simulation variants), whereas in the area nearby the back face, the strains were determined by the method outlined in Figure 14, i.e. around 5%. By deriving the results with the highest values, we were able to determine the maximum values of the strain rates, namely $1.16 \cdot 10^5 s^{-1}$.

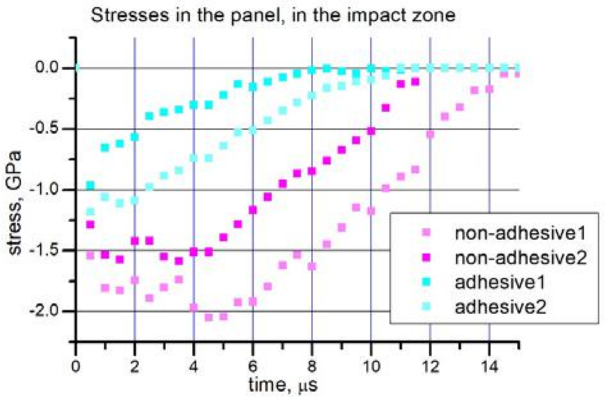

Figure 15. Stresses in the elements nearby the impact zone

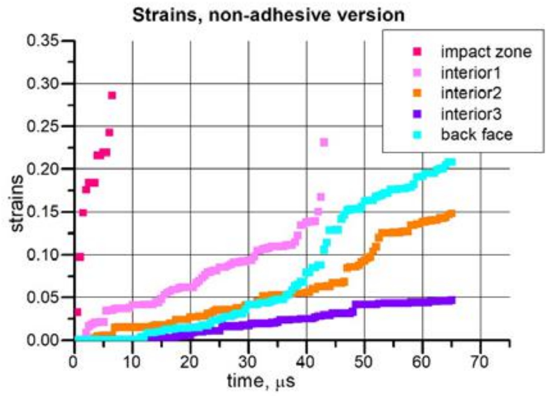

Figure 16. Strains in elements nearby the symmetry axis, non-adhesive simulation version

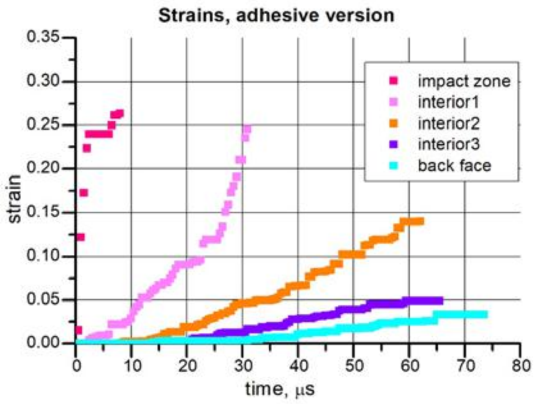

Figure 17. Strains in elements nearby the symmetry axis, adhesive simulation version

IV. Conclusions and Perspectives

Throughout this article, the authors aimed to demonstrate that the UHMWPE laminate materials, such as Tensylon®, can be efficiently approached through numerical simulation by using simple and accessible constitutive models, such as the plastic kinematic model available in the LS-Dyna® from ANSYS® simulation package. This model requires the use of only a few critical properties, such as the Young modulus, the Poisson ratio and the tangential modulus.

The representation of the material is also very important. For example, even if an orthotropic model is chosen, but the representation has a continuous shape, i.e. a macroscopic approach, the delamination phenomena won't be observable. By representing the material on layers level, through the manipulation of the contact, fail or eroding conditions, the behavior of the material can be controlled at meso-scale level even by using a simple material model, with very few parameters.

The simulations performed constitutes into two versions:

- a simple representation of homogenous, uniform layers, which correspond to the Tensylon® pre-preg layers, having the same thickness as in reality; and

- a more complex representation, by introducing extra layers of adhesive between the pre-pregs. This version proved to have both advantages and disadvantages. On the one hand, it evidenced more the visco-elastic character of the material, on the other hand, it proved a weaker performance (by allowing a deeper penetration). It is to be noted, however, that polymeric materials are, usually, strongly dependent on the strain rate and the previous states of the material, therefore, in order to obtain a more reasonable solution, one should determine a different set of input properties, which would denote a tougher material, such as the UHMWPE.

As a future prospect, in order to advance faster with the determination of a more appropriate set of UHMWPE laminate input properties for the plastic kinematic model in LS-Dyna, a simpler representation, with thicker layers could be approached. Also, more experimental testing would be required in order to validate the obtained model.

As a general conclusion, we reproduce an axiom with which we agree and which seems to be very popular among the numerical simulation tools users nowadays, claiming that "It is of more interest to find good designs given the limitations of the resources and time available rather than the best possible design" [10].

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