2D laminated and 3D warp interlock fabric under high velocity impact

Benjamin PROVOST [1, 2], François BOUSSU [1, 2], Daniel COUTELLIER [1, 3]
[1] *Univ. Lille Nord de France, F-59000 Lille, France;*
[2] *ENSAIT, GEMTEX, F-59100 Roubaix, France;*
[3] *UVHC, LAMIH FRE CNRS 3304, F-59300 Valenciennes, France;*

Context of the study

Conventional amour shield is mainly oriented on metallic materials which are well-known for decades.
Nevertheless, performances of those protections are required to be more and more efficient especially since the apparition of non conventional threat on the battlefield. The weight is also nowadays one of the most important parameter which can no longer be neglected. Armoured vehicle manufacturer are indeed looking forward for every solution which offer the possibility to reduce the mass of components.
The mass of the armoured shield is generally the one mainly influent and the weight reduction is one of the key parameter to reduce the fuel consumption, increase the payload, and offer more manoeuvrability to vehicles. [1]
However, the difficulty is to reduce as safe as possible the total mass of the protection solution and ensure the safety of the vehicle. One of the possible solution is to use new combination of materials, able to be more efficient against new threats and lighter than the traditional steel armour.
It's in this context that the combination between some well-known ballistic alloys and textile composite material appear as a high potential solution for armour plated protection.
Indeed, used as a backing, textile composite material have real interesting properties such as a very low density compared with steel and good behaviour in term of ballistic efficiency.
Those textile composite backings, which have been widely used in the aerospace sector, are nowadays more and more used for land vehicles.
Improvements on textile composite backings, by optimizing the parameters of the fibrous reinforcement or the resin and its process, are widely awaiting.
Some studies have been led in order to understand the impact behaviour of those composite materials. Nevertheless, new treats such as high velocity projectiles (steel projectile accelerated from 1000 to 2000 m/s or more) have been identify. Those non conventional threats impact the protection according to a not well-known behaviour which needs to be adapted to the armour protection.

Experimental study

In order to study the difference of behaviour of these proposed solutions submitted to high speed impact tests, two different kinds of backing have been achieved.
The first one is a classic 2D laminated composite, made of several pre-impregnated plies made with yarns of 3360dTex linear density. (Those composites are widely used in hard ballistic protection). Those plies are assembled under high heat and pressure.

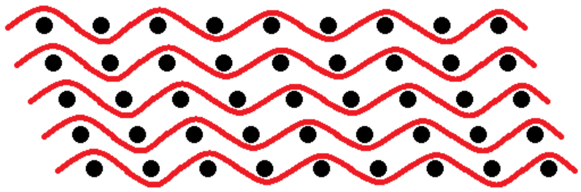

Figure 1: Assembly of 2D laminated Prepreg

The second type of backing is a 3D warp interlock fabric composite designed in the GEMTEX laboratory. The main characteristic of those fabrics is their unusual bonding between plies created by the specific evolution of given warp yarns through the fibrous structure.

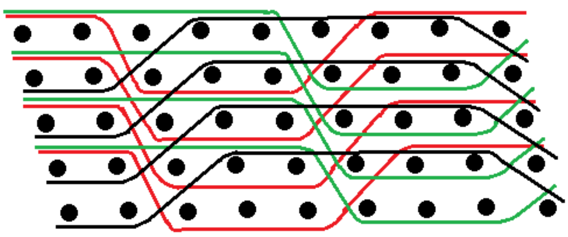

Figure 2: schematic view of one ply of 3D warp interlock fabric.

3D warp interlock fabric have different mechanical properties than 2D fabric made of the same material [2][3][4][5].

Experimental results

From a theoretical point of view, we expect that in the same conditions of test (same projectile, same impact angle and velocity), those two reinforcements will have a different behaviour.
We already know that the 2D composite will present a classic reaction under impact, a mix of shear stress, tensile stress and delamination, especially on the back layers of the composite. The behaviour under impact of the 3D reinforcement is more complex to expect because of it novelty.
Thanks to these tests, it has been possible to observe that the 2D laminated composites have a classic behaviour under impact, a behaviour which has been observes and describes any many papers. They are 3 main type of mechanical stresses which are working to disperse the remaining energy of the projectile: the shear stress, the breaking tensile stress, and the intra-ply delamination (mode II of rupture). The two firsts are present in every material subjected to impact but the delamination is specific to those assemblies of plies glued together.
The intra-ply delamination dissipates a certain amount of energy due to the friction of plies between each other and tensile resistance of warp yarn interlocking located in the thickness of the final material. This generally creates a bigger damaged area and weakens the rest of the backing composite.
3D warp interlock fabrics composite have a very different behaviour under impact. We can observe first of all that the damaged area is much smaller on the 3D, the impact is more localised. Indeed, the first ply of 3D warp interlock fabric is fully shear, the second one in the middle, had a mechanical effort which is a mix of shear and tensile stress while the last one have only tensile stress.

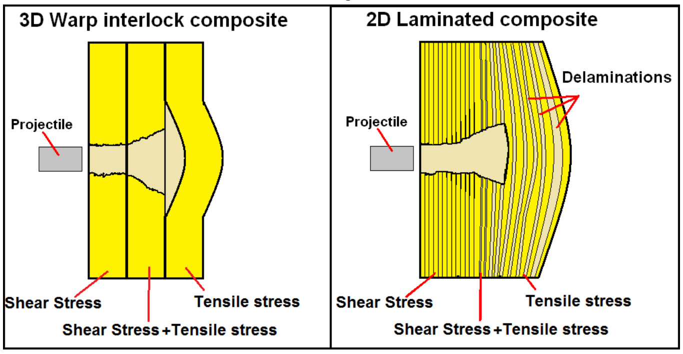

Figure 3: Observation of damages on 2D and 3D

The fact that the 3D reinforcement allows no delamination (except sometimes between the 2 last plies), means that the 3D is generally impacted deeper in the thickness due to the non absorption of energy during the delamination process. However, the 3D composite remains able to absorb another impact thanks to it localized damage area contrary to 2D laminated reinforcement.

Conclusion:

This campaign of tests confirm the hypothesis that 2D fabric composite and 3D fabric composite both have a different behaviour under a same impact.
Indeed, 2D fabric composites have an expected reaction while the 3D fabrics present a new mechanical response.

Acknowledgments

I would like to thanks the ISL for carrying out all the tests and NEXTER SYSTEMS for giving me the opportunity to work on the improvement of textile backing composite.

References

[1] Antonio Miravete, 1999 , « 3-D textile reinforcements in composite materials » , WP, ISBN-13: 978-1-85573-376-3

[2] F Chen and J.M.Hodgkinson, "Impact behaviour of composites with different fibre architecture", Proc. IMechE Vol. 223 Part G: J. Aerospace Engineering, JAERO451
DOI: 10.1243/09544100JAERO451

[3] Julian HU, "3D fibrous assemblies, properties applications and modelling of three dimensional textile structures", WP number 74, page 105, ISBN 978-1-84569-377-0, 2008

[4] Ashok Bhatnagar, "Lightweight ballistic composite", 2006, WP,
ISBN-13: 978-1-85573-941-3

[5] F.Boussu X. Legrand and A.Serret, "General clustering of warp interlocks structures" ITMC 2007 International Conference