FABRIC IMPACT DROP TESTS: NUMERICAL SIMULATIONS USING THE LS-DYNA MICROMECHANICAL APPROACH AND EXPERIMENTAL CHARACTERIZATION

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FLY-BAG Project
"Advanced technologies for bomb-proof cargo containers and blast containment units for the retrofitting of passenger airplanes"

The FLY-BAG project developed and tested a textile based luggage container able to resist to the blast of explosives hidden in the luggage loaded in the cargo holds. The project received a lot of acknowledgements, (Premio Nazionale per l'Innovazione 2012, TECHTEXTIL PRIZE 2011 Frankfurt, Design Technology Award 2011 MATERIALICA Munich, Innovation Convention 2011 Brussels). Moreover an European patent was filed. On the basis of the success of FLY-BAG, ended in 2011, CETMA and the other project's partners are working on the FLY-BAG2 European project, "Advanced technologies for bomb-proof cargo containers and blast containment units for the retrofitting of passenger airplanes"; the aim is to optimize the "FLY-BAG cargo version", to develop a "FLY-BAG passenger cabin version" and to carry out full scale explosion tests on dismantled airplanes. The partner involved in the FLY-BAG research project came from 7 European countries, like research center and small and medium enterprise : D'Appolonia S.p.A. (Italy) the project coordinator, STFI (Germany), Blastech (UK), Cargo Network (Netherland), APC Composite (Sweden), University of Patras (Greek), DoKaSch Air Cargo Equipment (Germany), Ziplast (Italy), Aernnova Engineering Solutions (Spain), INASCO Integrated Aerospace Sciences Corporation (Greek), EASC European Aviation Security Centre (Germany), Meridiana Maintenance S.p.A. (Italy). CETMA is responsible of the numerical simulation workpackage, the aim is to calibrate and to predict with finite element models all blast events in order to support and to optimize the design of the blast resistant devices.

Web site: www.fly-bag2.eu

Progetto FLY-BAG
"Tecnologie innovative per lo sviluppo di container e sistemi di mitigazione di esplosione per la zona cargo e la zona passeggeri di un aeromobile"

Il progetto FLY-BAG ha sviluppato e testato un contenitore per bagagli in materiali avanzati, compositi e tessuti tecnici, per il settore aeronautico, in grado di resistere all'esplosione di un ordigno nascosto all'interno di un bagaglio caricato in stiva. Il progetto ha ricevuto numerosi riconoscimenti (Premio Nazionale per l'Innovazione 2012, TECHTEXTIL PRIZE 2011, Design Technology Award 2011 MATERIALICA, Innovation Convention 2011). É stato, infine, depositato un brevetto europeo. Sulla base del successo del progetto FLY-BAG, terminato nel 2011, il CETMA, insieme ai Partner di progetto, sta lavorando al progetto di ricerca FLY-BAG2 "Advanced technologies for bomb-proof cargo containers and blast containment units for the retrofitting of passenger airplanes", che prevede l'ottimizzazione del dispositivo "versione cargo", lo sviluppo di un dispositivo analogo "versione cabina passeggeri" ed i test di esplosione con dispositivi full scale su aerei dismessi. Il gruppo di ricerca comprende 13 partner da 7 Paesi Europei, tra cui centri di ricerca e piccole-medie imprese altamente specializzate: D'Appolonia S.p.A. (Italia), coordinatore del gruppo di lavoro, STFI (Germania), Blastech (Regno Unito), Cargo Network (Olanda), APC Composit (Svezia), University of Patras (Grecia), DoKaSch Air Cargo Equipment (Germania), Ziplast (Italia), Aernnova Engineering Solutions (Spagna), INASCO - Integrated Aerospace Sciences Corporation (Grecia), EASC - European Aviation Security Centre (Germania), Meridiana Maintenance S.p.A. (Italia) e CETMA. Nell'ambito del progetto il Consorzio CETMA è responsabile del workpackage di modellazione numerica, il cui obiettivo è di sviluppare tutte le attività di simulazione numerica dei fenomeni esplosivi di supporto allo sviluppo e ottimizzazione dei contenitori resistenti alle esplosioni.

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SUMMARY

Least Risk Bomb Location (LRBL) regulation represents a challenge for aircraft manufacturers. On the basis of this standard, in the EU research project FLY-BAG2, an innovative containment system has been designed to reduce the effects of on-board explosions. In this project, as main result, a blast resistant flexible container characterized by a multi-layered high performance textile with composite reinforcements has been developed. In this paper the behaviour of the main textile materials has been analysed by means of LS-DYNA code. In particular, the fabric drop test has been modelled and simulated. The numerical model derivation utilizes the micro-mechanical approach and the homogenization technique. The LS-DYNA results have been compared with the experimental data to calibrate the numerical material model and to evaluate the performance of the technical textiles. Finally, the main parameters of the textile have been identified, bringing evidence of the numerical model capability to simulate the impact behaviour of woven fabrics.

Keywords
Drop tests, dry fabric simulation, LS-DYNA, mat 235, micro mechanical, RVC.

INTRODUCTION

Terrorists have proven that could be able to circumvent security scans both by carrying explosive devices on-board themselves or hidden in luggage. At present, all efforts are focused on attenuating the effects of an in-flight explosion by providing complementary passive protective structures, both for the cargo hold and passenger cabin [1]. In FLY-BAG2 has been designed an innovative blast mitigation solutions. The idea has been to develop a compact blast resistant flexible and foldable luggage container based on a multi-layered high-performance textile structure with composite reinforcements [2][3].
In this paper the behavior of fabrics, used in FLY-BAG2 mitigation devices, has been analysed by means of LS-DYNA code; in particular, a procedure has been improved to handle all material and numerical parameters to get reliable material models. In this study the synergy between experimental drop test and numerical simulations has been fundamental to evaluate the performance of the technical textiles and to calibrate the LS-DYNA material model.

EXPERIMENTAL IMPACT DROP TEST ON FABRIC

An important characteristic of the textile structure is the capability, for trapping accelerated luggage fragments during a blast event. Therefore, the Fractovis impact tester has been used to investigate the fly bag (Figure 1(a)). Moreover, a custom clamping system has been realized (Figure 1(b)) to reduce the sliding of the textiles during the dart impact.

(a) (b) (c)

Figure 1: Impact drop test

The comparison of all the tests results on different fabrics has allowed to select the best performing configuration: Innegra and Twaron woven fabric (Figure 1(c)). The calibration of the numerical models has been focused on these materials; the curves Force - Time of the impact have been compared with the numerical simulation results.

NUMERICAL MODEL OF THE IMPACT TEST ON FABRIC

The numerical simulations have been carried out by means of the FE Explicit code LS-DYNA. A numerical model of the impact test on fabrics has been realized taking into account all relevant part of the testing device (Figure 2). The dart has been modelled through the *PART_INERTIA card. The *INITIAL VELOCITY is assigned, taking into account the equipment inertia property and the energy of the test to be simulated. The constraints applied to the dart allow only Z displacement (direction of the gravity), as in the testing device [4]. The flanges have been modelled as rigid body; they are constrained in the X-Y plane and in Z direction with an additional preload (bolts) and an external clamping device.

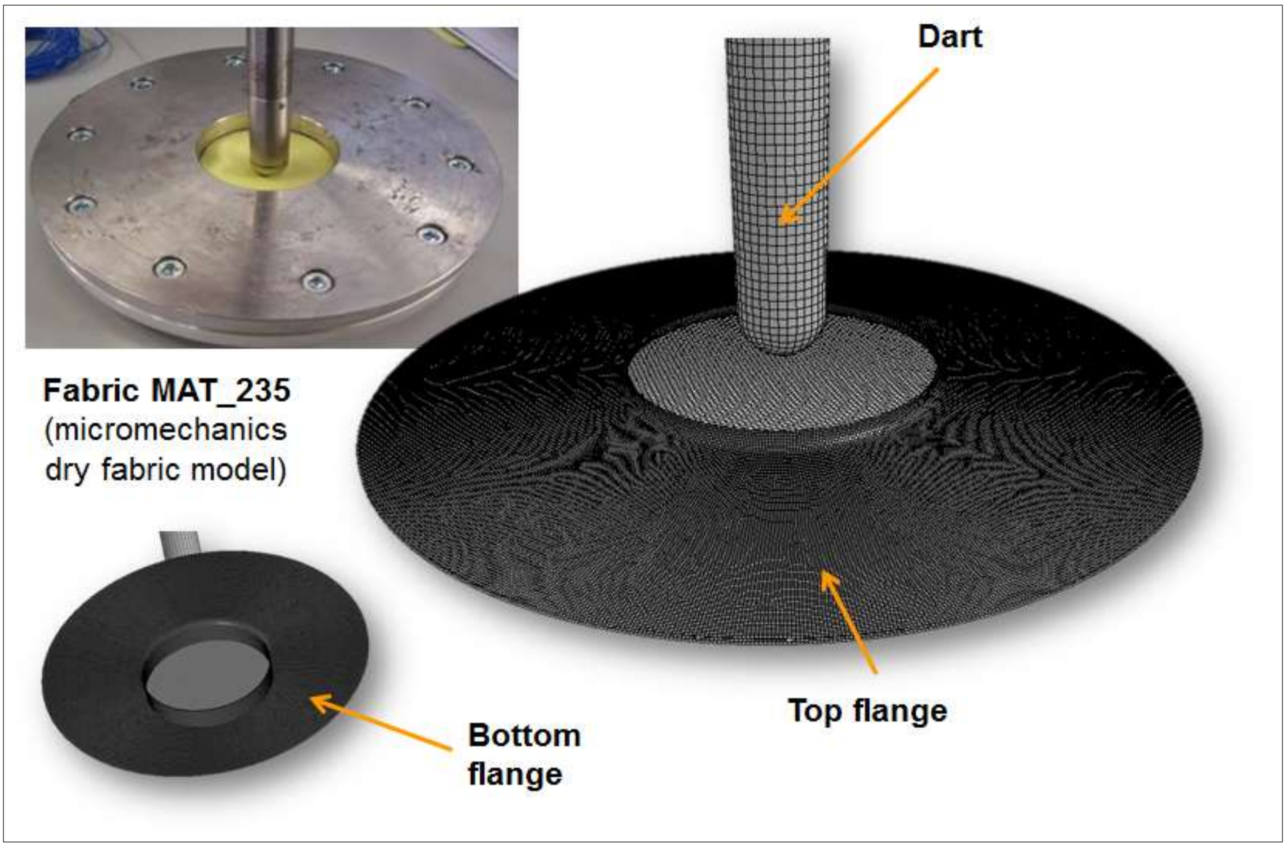


Figure 2: FE model

The LS-DYNA material model, selected for the simulation of the fabrics behaviour, has been the *MAT_235, which uses the micromechanical approach, taking into account the yarn interaction. This model is based on the Representative Volume Cell (RVC) that represents the periodic structure of the fabric (Figure 3). The direction of the yarn is determined by two angles, the braid angle, "θ", and the undulation angle, "β", which is different for the fill and warp yarn. The pre- and post-locking phase have been implemented in the model through the yarn stiffness matrix by a discount factor, "μ".

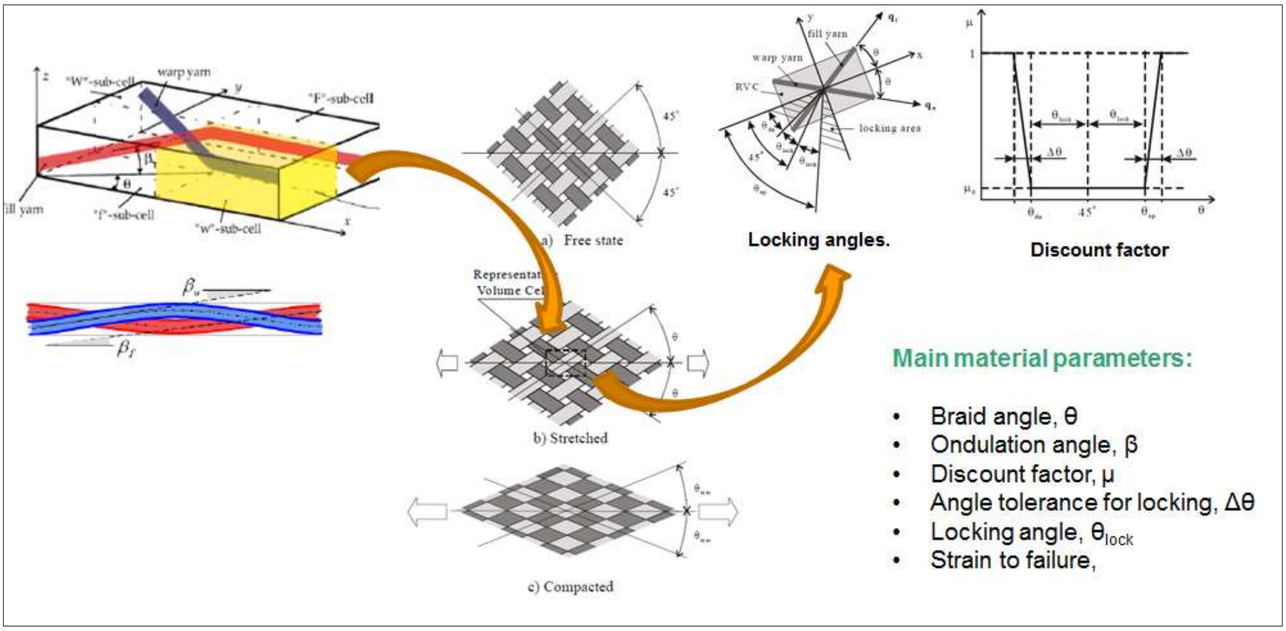


Figure 3: MAT_235 (micro-mechanics dry fabric model)

This factor is function of the braid angle and it changes from $\mu_0 = 0$ to $\mu = 1$. At beginning the discount factor is μ_0 and the material has a very small resistance to shear deformation. In this way, the material behaves like a trellis mechanism with poor resistance against the rotation of the yarns, corresponding to the friction between them. When the locking occurs, the fabric yarns are packed and they behave like an elastic material. The discount factor is $\mu = 1$; in this case the fabric resists with its real shear modulus [5].

SIMULATION RESULTS AND MATERIAL MODEL CALIBRATION

Simulations have been performed to reproduce the behaviour of the Innegra and Twaron fabrics in impact drop test. In Figure 4 the evolution of the failure in the Innegra fabric during on impact with a dart is reported. After that, the simulation results have been compared with the experimental curve in order to calibrate the material model.

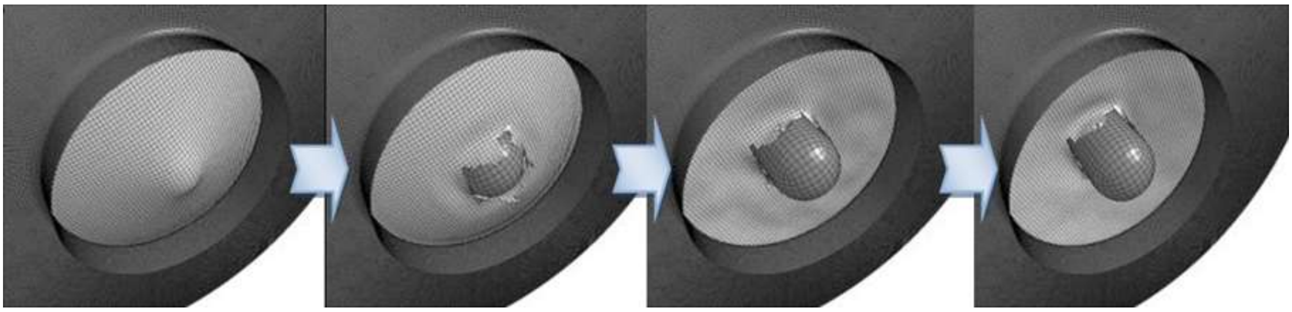


Figure 4: Evolution of the failure of the fabric during the impact with the dart

In this way, the Force - Time curves of the 15 J drop test on Innegra and Twaron and the simulations results are reported in Figure 5. The comparison and numerical data shows the level of confidence and reliability of the material model. In fact the back face of the composite exhibits the same dimension and geometry of the perforation area in both cases.
An additional drop test simulation has been carried out with two layers of Innegra and 30 J of impacting energy. The results of this simulation has allowed to evaluate the reliability of the LS-DYNA contact (*CONTACT_AUTOMATIC_SINGLE_SURFACE) algorithm between the different layers of the fabrics. The comparison of the two curves, experimental test and numerical simulation, is shown in Figure 6: on the left two layers of Innegra after impact and the numerical model are compared. Also in this case, the dimensions and the shape of the failure area, due to the impact with the dart, have been equivalent.

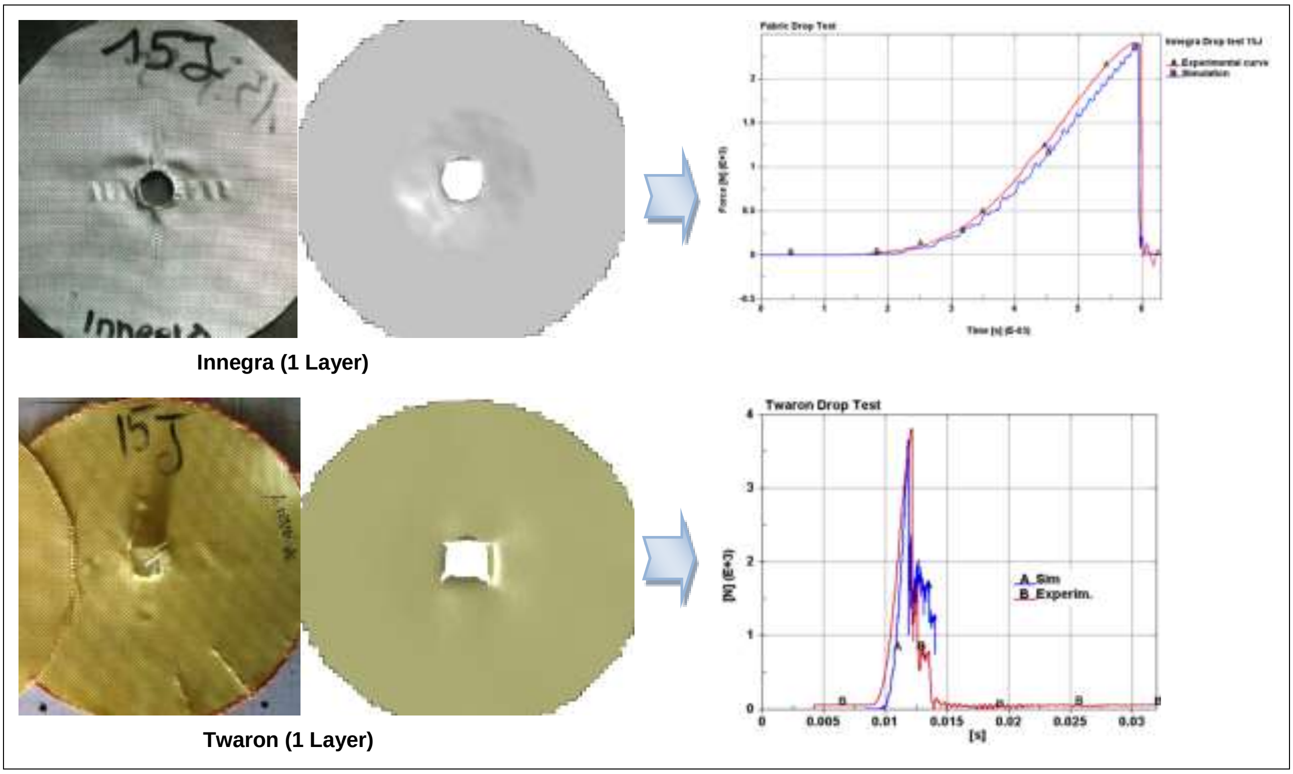
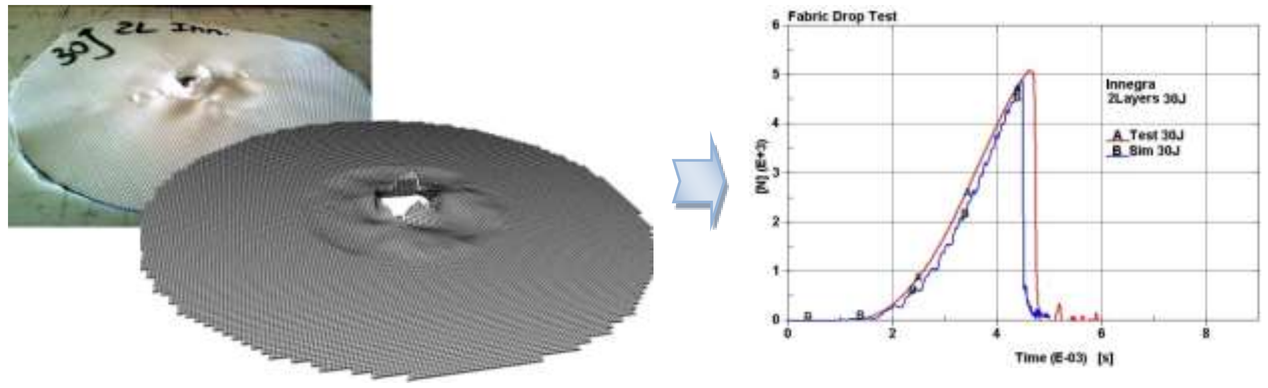


Figure 5: Innegra and Twaron fabric after the 15 J drop test and the simulation results



Innegra (2 Layers)

Figure 6: 2 Layers of Innegra fabric after the 30 J drop test and the simulation results

The calibration of the material parameters has been carried out using optimization techniques and the tool LS-OPT which has a feature dedicated to the parameter identification. It permits either a contemporaneous variation of all input parameters and a fast individuation of the best configurations in term of matching of simulation results and experimental data, moreover it is possible a comprehension of parameters influence on impact behaviour. The integration of the LS-DYNA FE model into LS-OPT is roughly described by the workflow in the following Figure 7.

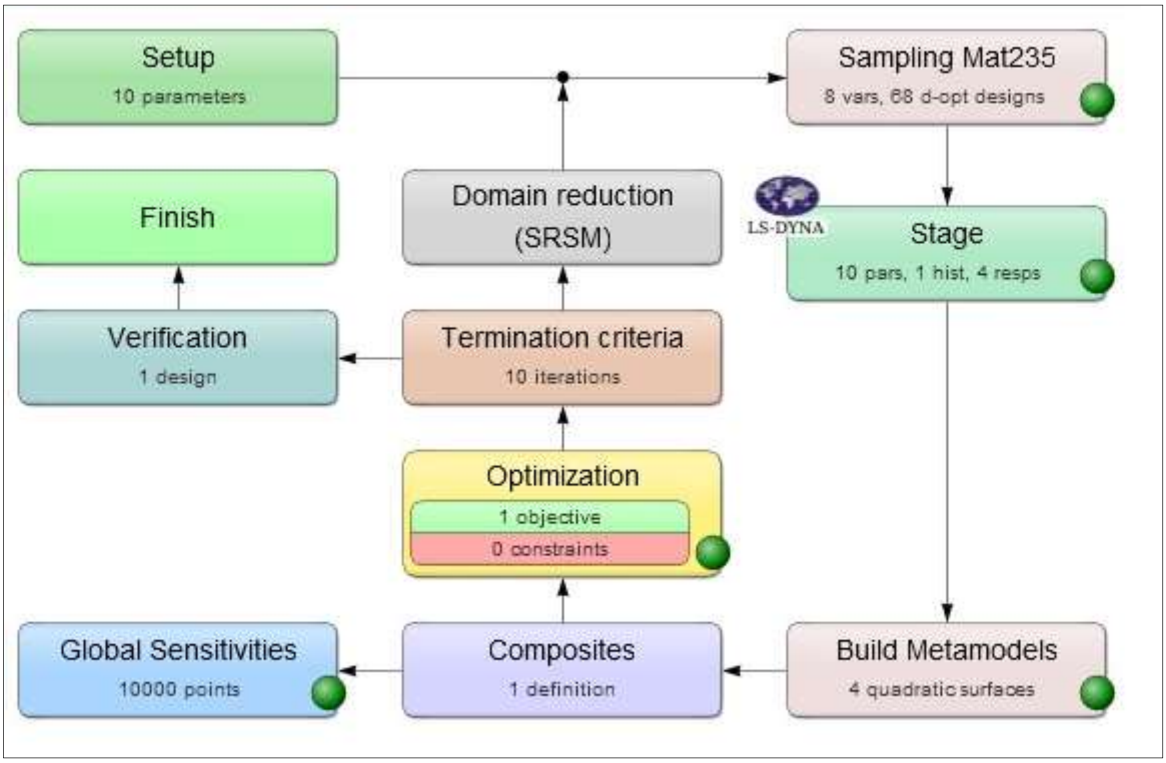


Figure 7: LS-OPT workflow

In particular, the "setup" block defines the material input variables and their suitable range of variation. These input variables have included: longitudinal and transversal elastic modules (e_1 and e_2), shear modules (g_{12} and g_{23}), Poisson's ratio (v_{12}), discount factor (dscf), locking angle (thl) and angle tolerance for locking (atlr). Each time that a new combination of their values has been proposed by LS-OPT (Sampling Mat235), the LS-DYNA input file has been updated and a new LS-DYNA analysis has been performed in bath mode (Stage). Then the output of each simulation has been post-processed and the analysis results have been valuated (Build Metamodel). The output used in this study has been the reaction Force - Time history. These numerical results have been compared with the experimental data and the relative mean square error (MSE) has been computed. Such error has been the objective function to be minimize (Composite and Optimization). At each iteration if the solution was not converged, the process started all over again and variables domain has been reduced by means of a domain reduction block in order to increase the accuracy in the region of interest and to accelerate the convergence.

In Figure 8 the most important parameters values as function of iteration numbers are shown. The optimization process converges after 10 iterations.

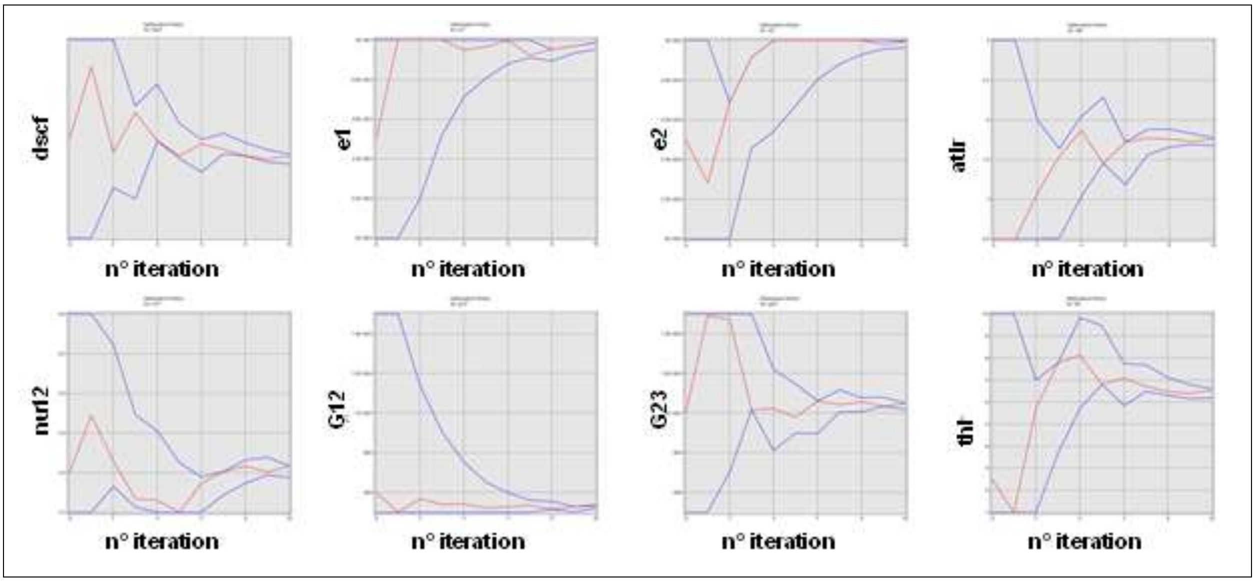


Figure 8: Parameters optimization history

The sensitivity analysis (Figure 9) and the correlation matrix results (Figure 10) have allowed to evaluate the performance of the fabric in relation to the main material parameters. The behaviour of the fabric is basically governed by the elastic modulus, Poisson's ratio and the shear modulus. Their specific influence is highlighted in Figure 11. On the contrary, the effects of the locking angle and the discount factor are negligible.

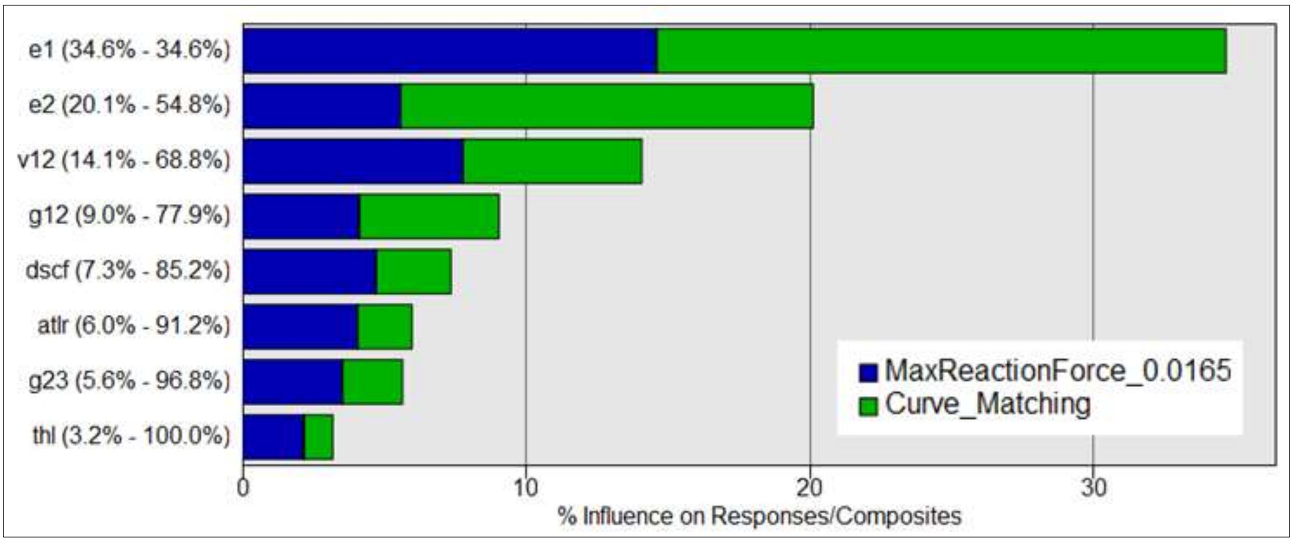


Figure 9: Global sensitivity plot

Figure 10: Correlation matrix

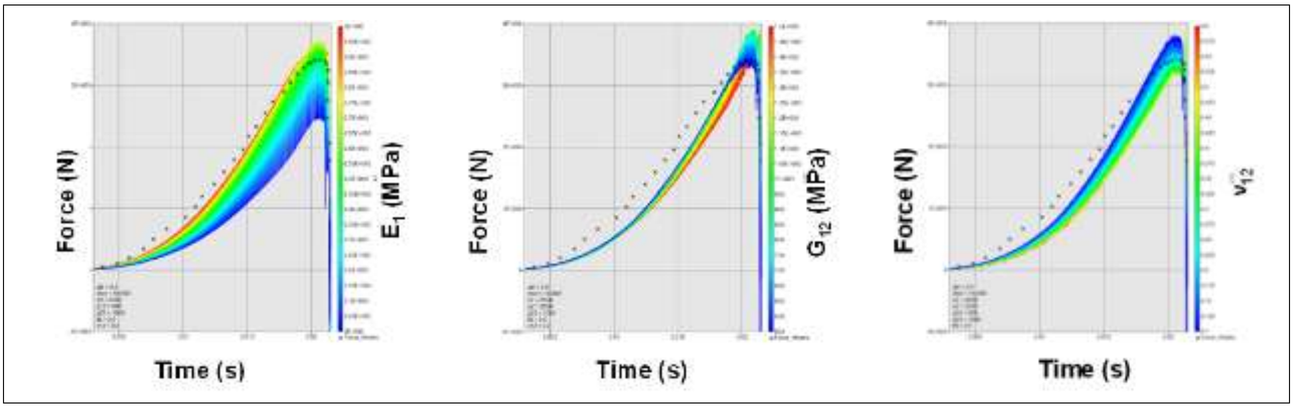


Figure 11: Sensitivity analysis ,influence of E_1, G_{12}, v_{12} during the impact on the Force - Time curve

CONCLUSIONS

In this work, the parameters calibration of the LS-DYNA 235 - material model has been defined for Innegra and Twaron. An automatic methodology has been set up that permits, through the use of an optimization tool LS-OPT, the full management of the material parameters. Moreover, the direct comparisons of simulation results with the experimental data has gained the extraction of pertinent material parameters for the best fit.
The optimized material model has allowed to analyse the reliable behaviour of the fabrics and it will be used to simulate the blast event in the mitigation devices of the FLY-BAG2. The matching of the experimental test with the numerical simulation has been the key strength of a robust analysis process.
In the future, due to LS-OPT matching flexibility, this methodology can be applied to characterize several material models in LS-DYNA code environment for aerospace applications.
Further research steps will be addressed to include full-scale test and to model of the system in real operative conditions, as well as blast testing on-board dismissed airplanes leading to certification of the system.

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