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NLR-TP-98356

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by

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Abstract

Within the framework of a European BRITE EURAM project, several partners work together to evaluate and analyse “tensor skin” panels. Tensor skin panels are designed to improve the crashworthiness of composite helicopters in case of impact on water, by providing a quasi-plastic deformation behaviour. Tensor skin panels were designed, fabricated and tested as well as several equivalent conventional honeycomb core sandwich panels with identical face sheets. The panels were tested in static transverse load, static in-plane shear and at dynamic transverse impact.

This paper presents the panel configurations, the test conditions and the test results as well as the numerical simulation of these tests.

1. Introduction

When a helicopter crashes on solid soil, impact energy can be absorbed by the landing gear, the subfloor structure and the seats. The combination of these energy absorbing components leads to a reduced loading on the occupant. In case of impact on water, the landing gear is expected to be less efficient in absorbing energy because it cuts into the water. The bottom skin hits the water and large transverse pressure loads are exerted by the water surface on the helicopter bottom skin. In such a case, metal skin panels tend to rack along the rivet lines with large plastic deformations. Controversial composite sandwich panels fail by the large transverse pressure loads, because of their brittle nature and no load is transferred to the subfloor structure, which is designed to absorb energy. All the energy has to be absorbed by the seats. In this case the occupant is subjected to large forces, reducing the survivability.

To improve the crashworthiness of composite helicopters in case of impact on water, a “tensor skin” concept was developed at NLR. Skin panels based on the tensor skin concept behave more like metal panels as they show a capability to deform (indent) in a quasi-plastic mode. When the tensor skin concept is applied to the bottom skin panels of a helicopter, a capability is created to sustain the water pressure load and to transfer the loads to the substructure. By loading the substructure this can absorb the energy in the crushing mode for which it is designed (Figure 1).

2. Tensor Skin Concept

Figure 2 presents a cross section of a tensor skin panel. A practical application of this concept was found as a replacement of a standard honeycomb sandwich panel. In the tensor skin panel, polyethylene (PE)/epoxy layers form a corrugated core, while the face sheets are formed by conventional fibre reinforced carbon or aramid epoxy material.
The capability of the tensor concept to deform in a plastic mode is achieved by unfolding and stretching of the polyethylene layers in the corrugated core during

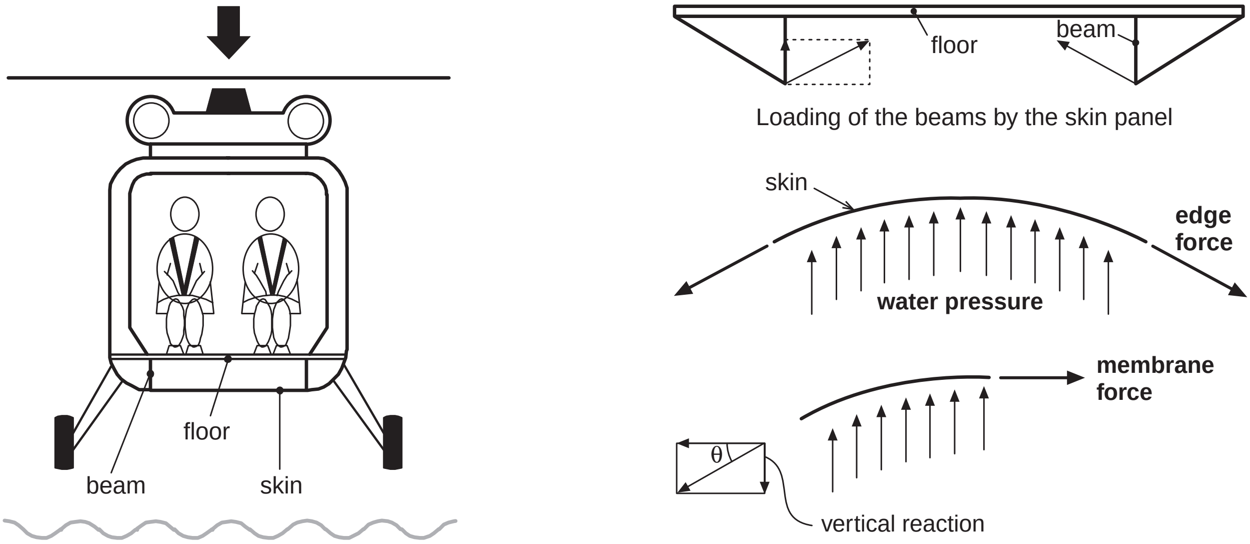

Figure 1: Force equilibrium of the bottom skin panel in case of an impact on water.

transverse loading conditions after the brittle surface layers have failed in an early stage. This concept is explained more extensive in reference 1.

The concept was shown to work well in quasi-static tests on square sandwich panels clamped along four sides (Ref. 2). Moreover, in an experiment on an assembly of two tensor skin panels and a sine wave beam (Fig.3), the sandwich panels were shown to survive the transverse pressure load that simulates the water pressure, and to transfer this load to the substructure, i.e. the sine-wave beam (Ref.2). The triggering mechanism of the sine wave was initiated and a crushing process was started, proving the feasibility of the design concept.

3. Experimental Results

Within the framework of a European BRITE EURAM project (Ref.3), several partners cooperate to evaluate and analyse the tensor skin panels. NLR designed and fabricated several tensor skin panels as well as several

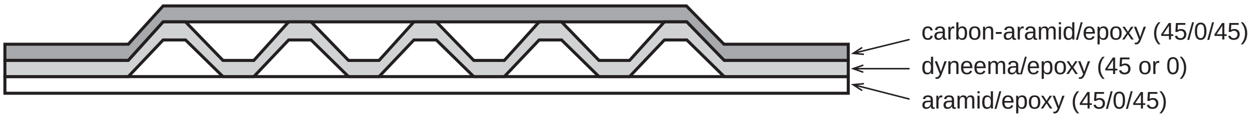

Figure 2: Cross section and lay-up of a tensor skin panel [Ref. 4]

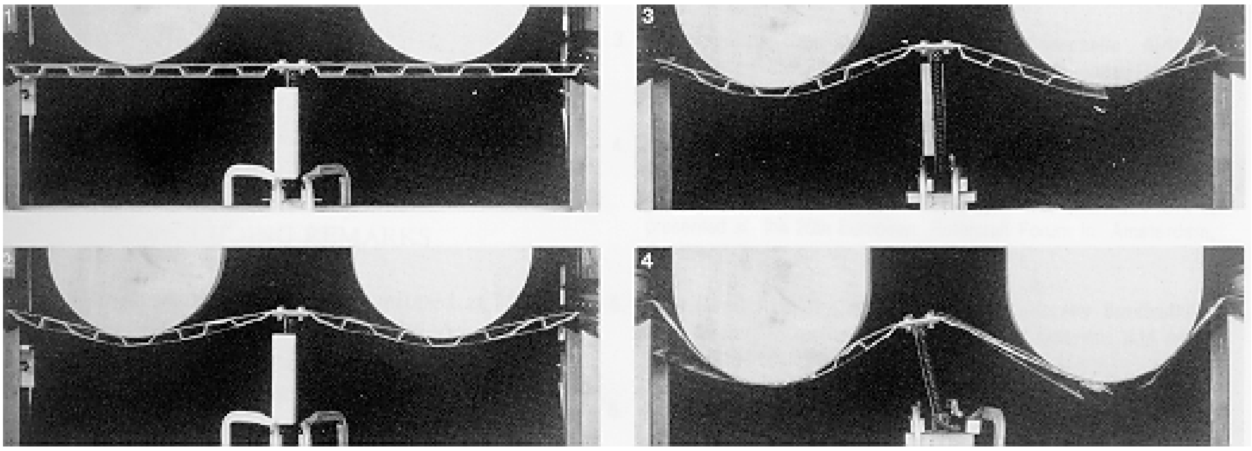

Figure 3: Assembly of two tensor skin stips and sine-wave beam loaded with a transverse load [Ref. 2]

Table 1: Summary of results from static transverse load tests on tensor skin panels

specimen id.	core of specimen	load at 1st peak (kN)	deformation up to 1st peak (mm)	maximum load (kN)	deformation up to 2nd peak (mm)
Panel 1	3 layers ±45 fabric	32	40	171	147
Panel 2	3 layers 0/90 fabric	31	42	75	140
Panel 3	2 layers ±45 fabric	35	43	51	143

equivalent conventional honeycomb core sandwich panels with identical face sheets. The panels were tested in static transverse in-plane load and shear at NLR, and by dynamic transverse impact at DLR.

Static Transverse Load Tests

Three static transverse load tests were performed two of which were already presented in references 2,4. The panels were clamped along four sides and a blunt indentor was pushed perpendicular to the surface into the skin. The indentor simulated the water pressure. Results of these tests are enclosed in table 1. The design requirement stated that sufficient load should be transferred from the skin to the substructure to initiate crushing of the substructure. Based on the first two tests, it was concluded that only panel 1 was able to transfer sufficient running load to the sine waves in the substructure to initiate crushing.

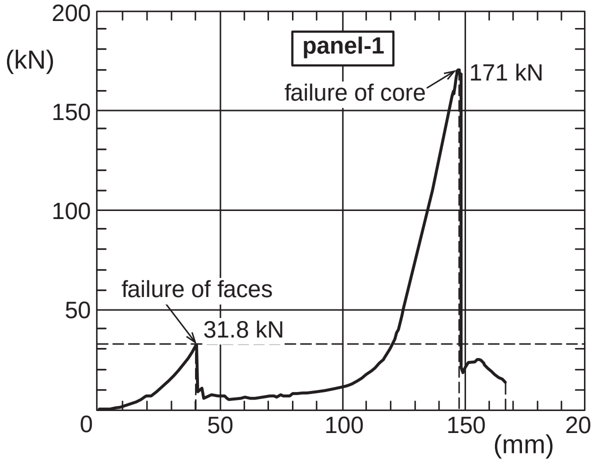

Figure 4: Measured impact force in a 3-layer PE/epoxy core configuration panel-1[Ref.2]

Figure 4 presents the test data of panel 1. In the first phase of the test the load increases until failure of the outer and inner faces occurred (first peak load 32kN). In the second phase unfolding of the PE core takes place at a reduced load level. After unfolding the core stretches and membrane stresses build up and finally the core fails (max. load 171 kN). In panel 2 a limited capability for shear deformation was present due to the 0-90 lay-up of the core. Unfolding of the 45 core of the other panels was accompanied by significant in plane shearing taking place at low loads, allowing large out of plane deformation.

Within the new project a new configuration (panel 3) was fabricated, based on the design of panel 1 but with only two layers PE/epoxy in 45 degrees orientation compared to panel 1. By removing one layer from the core, the weight was reduced. The test showed that this core layer did not have sufficient load carrying capacity, it was torn due to the smaller thickness. Based on these results, it is concluded that the 3-layer configuration with the 45 degrees orientation is the only feasible design.

Static Shear Tests

Static shear tests were performed to compare the stiffness (buckling) and strength behaviour with respect to the operational loading case. Two configurations were fabricated: a tensor skin with a 3-layer PE core and a skin panel with a honeycomb core (Ref.6).

Table 2: Comparison of shear stiffness and masses of tensor and sandwich skin panels

core of specimen	shear modulus (Gpa)	maximum load (N/mm)	mass (kg)	specific length (N/mm/kg)	specific shear modulus G* (Gpa/kg)
3 layers 45fa PE	15.3	144	1.22	118	12.5
honeycomb	16.8	175	1.07	164	15.7

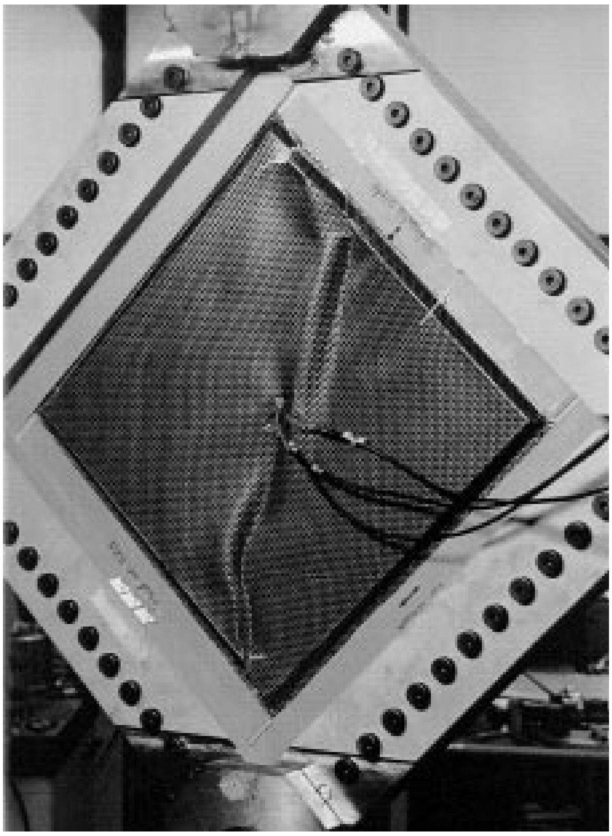

Figure 5: Shear test set-up with failed hybrid face of 3-layer tensor skin panel [Ref.6]

The panels were tested by NLR in a picture frame test set-up, by applying quasi-static in-plane shear loads as indicated in figure 5. The results of the shear tests are enclosed in table 2. The tensor skin panel was 14% heavier than the equivalent honeycomb core panel and both shear stiffness and load carrying capacity were lower. However, the tensor skin panel had not been optimised for this operational loading case, and improvement can be achieved by changing the lay-up of the faces or by adding an additional layer. The latter will results in a weight penalty.

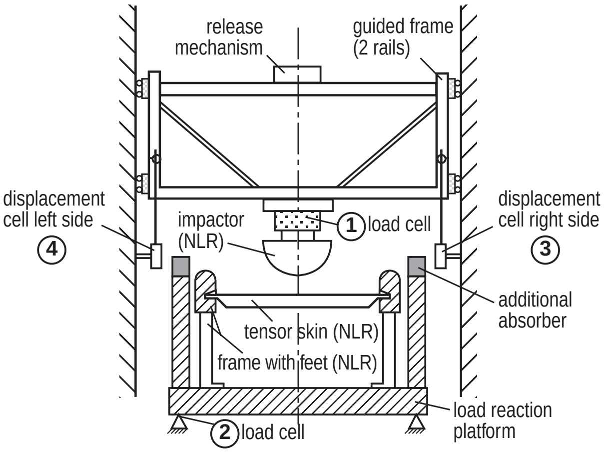

Figure 6: Test set-up for dynamic tensor skin tests [Ref. 7]

Dynamic Impacts

DLR performed three dynamic transverse load tests, by dropping a hemispherical aluminium impactor on clamped panels of the tensor skin and honeycomb configurations (Ref.7). The skin panels were fixed in a very stiff steel test frame as depicted in figure 6. This frame was fixed in the centre of the load-reaction platform of the drop tower. The hemispherical impact head with a radius of 150 mm has been fixed to a lightweight steel frame which is guided on either sides of the drop tower. A piezoelectric load cell was integrated in the fixture of the impact head to the guided frame. Besides the loads at the location close to the impact head and at the load reaction platform the displacement of the test frame was measured during the test with a sampling frequency of 200 kHz. In addition to the loads and displacement signals during the test the exact impact speed has been measured with a light barrier just before the impact.

Figure 7 presents the three damage skin panels. The largest damage can be found in the panel with the honeycomb core. The honeycomb core panel was penetrated, while the PE core of the tensor skin

Table 3: Summary of results from dynamic impact tests on skin panels

core of specimen	applied impact energy (kJ)	load at 1st peak (kN)	deformation up to 1st peak (mm)	maximum load (kN)	total deformation (mm)	absorbed energy (J)
2 layers 45 fabric	1.6	12.7	30.5	17.0	132.3	1021
3 layers 45 fabric	2.2	17.1	40.0	31.7	122.6	1630
honeycomb	2.2	25.9	36.9	25.9	>190	1100

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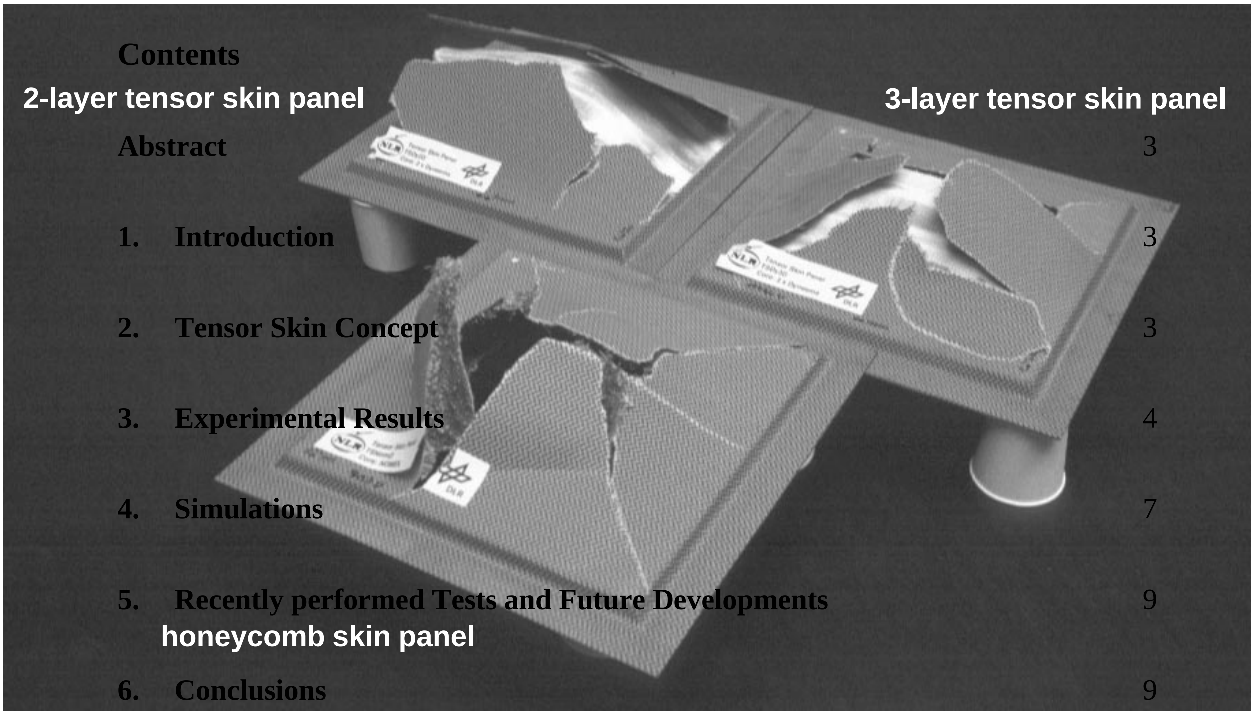

Figure 7: Comparison of post test damages of the skin panels [Ref. 7]

managed to stop the impactor. The two panels with the corrugated PE/epoxy core show a similar failure mode. In both panels the faces broke and the core unfolded. After the test the core of the 3-layer panel was intact and of the 2-layer panel was torn. The deformation of this 2-layer panel was larger than the 3-layer panel and therefore higher strains were present, resulting in fibre fracture and failure of the core. In table 3 the results of the dynamic tests are summarised. The evaluation of the results shows that the configuration with three layers of PE in the core gives the best results. Not only the 1st peak load is reduced compared to the honeycomb panel, also the maximum energy absorption is combined with the smallest deformation, and the impact force is transferred to the surrounding clamping without failure of the core.

4. Simulations

The University of Patras analysed the failure behaviour of composite structures using the PAM-CRASH finite element code (Ref. 8, 9, 10) of which the results are used in the present paper to compare with the test results. Failure behaviour of composite components under compression were simulated as well as tensor skins subjected to static transverse load, shear loads and dynamic impact. A similar numerical study was conducted by the University of Limerick (ref. 11)

(9 pages in total)

Simulation of Components and static transverse Load Tests

Specific material models were developed using the test results of composite components. Examples of the components are square beams, tensor skin strips and sine-wave beams. The models were compiled with 4-node shell elements with anisotropic material behaviour. The material properties were defined using stiffness, strength and damage progression data. The load deflection behaviour was well predicted for these components and agreement was observed between the calculated and measured tool forces. It was concluded that with the developed material models, the ability was created to model the static shear and dynamic transverse impact tests.

Simulation of static Shear Tests on Skin Panels

Both shear tests, which were performed by NLR were simulated by the University of Patras using PAM-CRASH. The behaviour of the strains of both the tensor skin panel and the honeycomb panel are quite similar. Unfortunately direct comparison of the data is currently not possible as not all data is recovered yet.

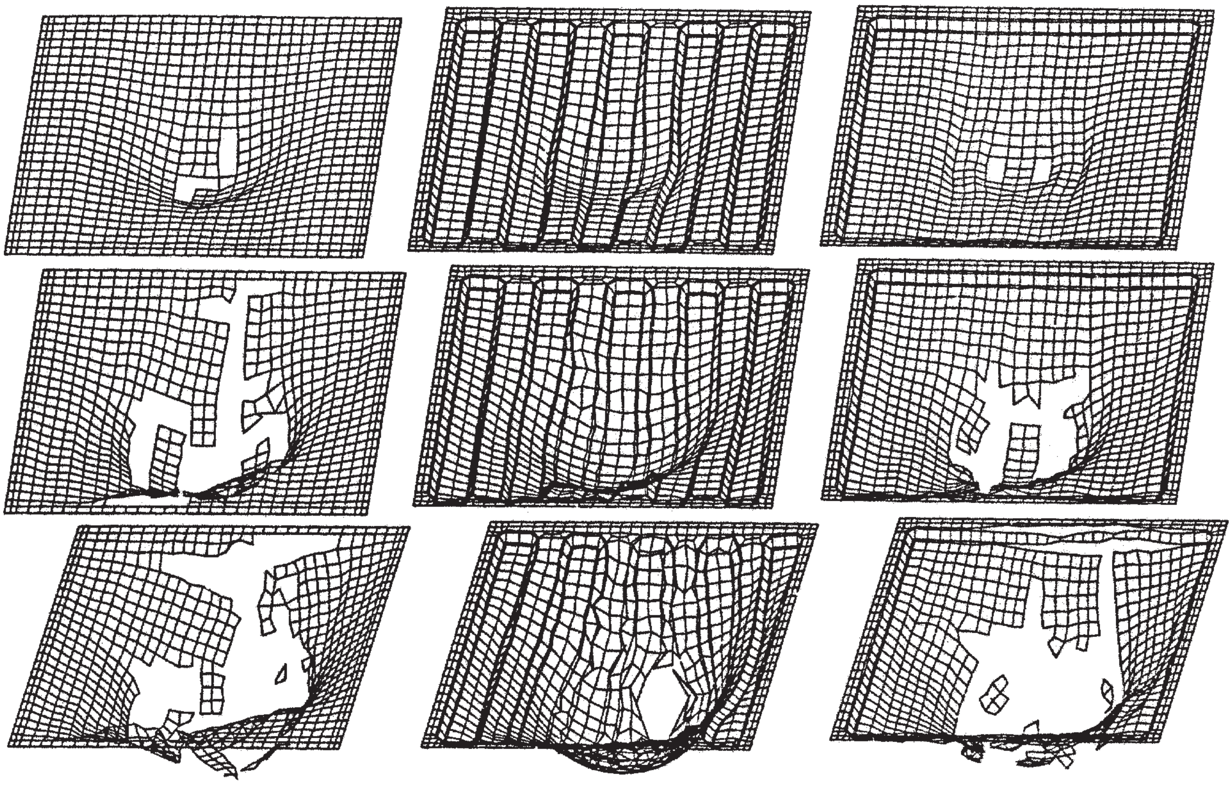

Figure 8: *Calculated deformed shapes of the aramid (left), PE (middle) and carbon/aramid hybrid (right) faces of the 3-layer tensor skin panel at various time intervals [Ref. 9]*

Simulation of dynamic transverse Impact Tests on Skin Panels

All three dynamic tests, which were performed by DLR, were simulated. Figure 8 shows the deformation of the three faces at various time intervals of one of the panels. In table 4, the results of the dynamic analyses are compared with the results of the experiments. Peak loads of the first, second and third peaks are presented with their corresponding displacements. A good agreement is found between the calculated and measured forces and displacement for both the tensor skin panels. The results of the honeycomb panels show less agreement. The modelled honeycomb adds too much stiffness to the sandwich structure. No solution has been found yet.

It is concluded that the PAM-CRASH FE-code has been successfully applied for the simulation of the failure process of crashworthiness composite sub-floor components. The developed composite material damage models are capable to represent successfully the degradation of the properties. The failure process of all the simulated structures was predicted and agreement is observed between the calculated and measured forces.

Table 4: *Comparison between test and simulation of tensor skin panel under transverse impact load*

specimen id.		max. displacement (mm)	1st peak		2nd peak		3rd peak	
			load (kN)	displacement (mm)	load (kN)	displacement (mm)	load (kN)	displacement (mm)
3 layers	test	122.6	17.5	40	22.5	88	31.7	115
	sim	96	15.3	37	17.5	82	20.5	92
2 layers	test	132.3	13.0	30	14.5	78	17.0	108
	sim	100	13.0	25	16.8	50	16.5	98
honeycomb	test		25.9	38				
	sim		41.5	5				

5. Recently performed Tests and future Developments

Recently, two complete box structures including a tensor skin were tested, one on rigid soil and one on soft soil. Results of these tests will soon be presented. Simulations of these structures are currently being performed by the University of Limerick.

As the results of the dynamic tests of a complete structure on soft soil are promising, future developments are aimed at the impact on water of a tensor skin panel clamped in a frame. Based on these test results, a modified design might be developed which can be supported with numerical analyses as these tools are available now. With these tools a complete substructure including a tensor skin could be re-designed and finally an impact test on water of a complete substructure could be performed as final proof of the concept.

6. Conclusions

The static and dynamic transverse load tests on the tensor skin panels demonstrated that no weight reduction could be accomplished by reducing the number of PE layers in the core compared to the baseline configuration. A minimum of three PE/epoxy layers is needed to maintain sufficient strength to transfer the static impact load to the energy absorbing substructure.

The shear test on the skin panels demonstrated a smaller shear strength and stiffness for the tensor skin configuration compared to the honeycomb configuration. As the panels were not yet designed for shear strength, improvement might be possible by changing lay-up or adding an additional layer. The latter results in an additional weight penalty for the 3-layer tensor skin configuration.

The dynamic tests on the tensor skin panels showed much better crashworthiness behaviour than the honeycomb panels. Most importantly, the tensor skin is able to transfer the forces that act transversally on the surface, to the energy absorbing components in the sub-structure. Not only the peak load at impact is decreased by using the tensor skin concept, the energy absorbing capacity of the panel is also larger.

Finally, the developed analysis tools were shown to be able to predict the failure behaviour of the skin panels. Therefore in future developments, this analysis tool can be used in the design of more efficient composite crashworthy structures.

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