SIMULATION OF A METAL-THERMOPLASTIC COMPOSITE ASSEMBLY

S. Paroissien[1], P. Rozycki[2] and T. Renault[3]

[1] Institut de Recherche en Génie Civil et Mécanique (GeM), IRT Jules Verne, Chemin du Chaffault, 44340 Bouguenais, France
Email: simon.paroissien@irt-jules-verne.fr
[2] Institut de Recherche en Génie Civil et Mécanique (GeM), Ecole Centrale de Nantes, 1 rue de la Noë, 44300 Nantes, France
Email: patrick.rozycki@ec-nantes.fr
[3] Faurecia, 2 rue Hennape, 92000 Nanterre
, France
Email: thierry.renault@faurecia.fr

Keywords: Multimaterial, FEM, CMT-Pins, Assembly, Analytical

Abstract
Multimaterial assembly is one of the main answers of the car industry to weight reduction issues. As their introduction in the automotive industry is still recent, many multi-material solutions have not been tested in crash, endurance and specific loading. Pre dimensioning tools and numerical models are still very challenging. The present study aims at addressing some of these limitations. From the industrial issue of a seat back rest, an innovative multimaterial assembly based the CMT pin technology has been designed. A quasi static experimental campaign has been conducted to investigate several interface dispositions. From this experimental campaign, a numerical model with LS Dyna software and an analytical pre dimensioning tool are then proposed and compared. These first results encourage us to continue this study with future works to find the ideal texturing answering conception specifications and other optimisation issues.

1. Introduction

During the past decades, composites materials have taken more and more place in the transport industry. This is particularly true for the small series, where the price of the material have less impact on the production costs than in the large ones. One can take for example the evolution of structural composite percentage in the total weight of a plane in airbus production which goes from nearly 5% in the A300 (1972) to more than 50% for the more recent A350-900 XWB (2013). However, if composites are now common in this industry, their introduction in the large series of the automotive field is still very challenging. CO_2 emission standards required by various countries (Europe, USA, but also China) are forcing this sector to consider cutting edge solutions in weight reduction. The introduction of composite in structural applications is one of the main tracks, but this raises other issues like the way of joining the new composite parts with others that, for economic or structural reasons, will remain in metal. The joining method is a key choice so that the assembly can assure a safe load transfer while meeting the drastic specifications of the automotive industry. This study focus on the evaluation and simulation of a multimaterial structure, joined with a Cold Metal Transfer (CMT) pins interface, more precisely on the case of a front seat back rest. CMT Pin is a welding process patented by Fronius, an Austrian Society, allowing the welding of small pins on a metallic surface. Experimental investigations have been conducted on CMT process in [1-4] showing promising results on thermoset CFRP – Steel assembly

Excerpt from ISBN 978-3-00-053387-7

A thermoplastic composite (polyamide 6, dynalite) triangle is assembled to the head of a steel articulation mechanism thanks to a metallic disk textured by the CMT pin technology (Figure 1). CMT pins penetrate into the composite, locking the assembly in the transverse direction through a thermo stamping operation. A polyamide resin is added to avoid sliding between the two parts. Finally a second metallic triangle is welded to the articulation so that a moment could be transferred.

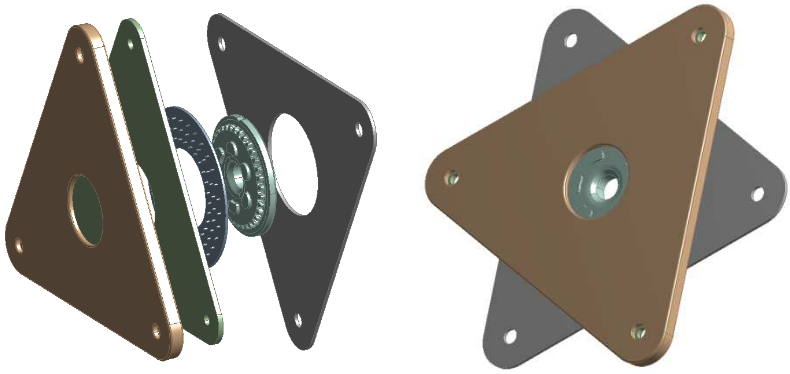

Figure 1. Assembly's geometry

2. Experimental campaign

2.1. Set up

The experimental results introduced in this article come from an experimental campaign leads by the Cetim in cooperation with Faurecia and Compose Tool for the project LIMECO. A torsional, quasi static solicitation is imposed to the triangular specimen. The specimen is free to translate along the rotation axis, to not over-constrain the assembly during the loading. Several pin dispositions have been tested and their performances compared.

Figure 2. Pin disposition

2.2. Result and discussion

For each configuration a good repeatability has been observed. Because of the overmolding, there was no visual access to the interface so following phenomenological explanations are based on post rupture aspects and numerical results. The maximal strength of the joint is ruled by pin behaviour but also by the direct adhesion of overmolding on the composite surrounding the interface. After slack compensation, the system reacts linearly to the solicitation. The stiffness is then smoothed by pins plastic comportment until reaching the maximal effort. Once the direct adhesion failed, the pins start to

Excerpt from ISBN 978-3-00-053387-7

be sheared. Total torque remains stable during this phase which ends with the total failure of the assembly.

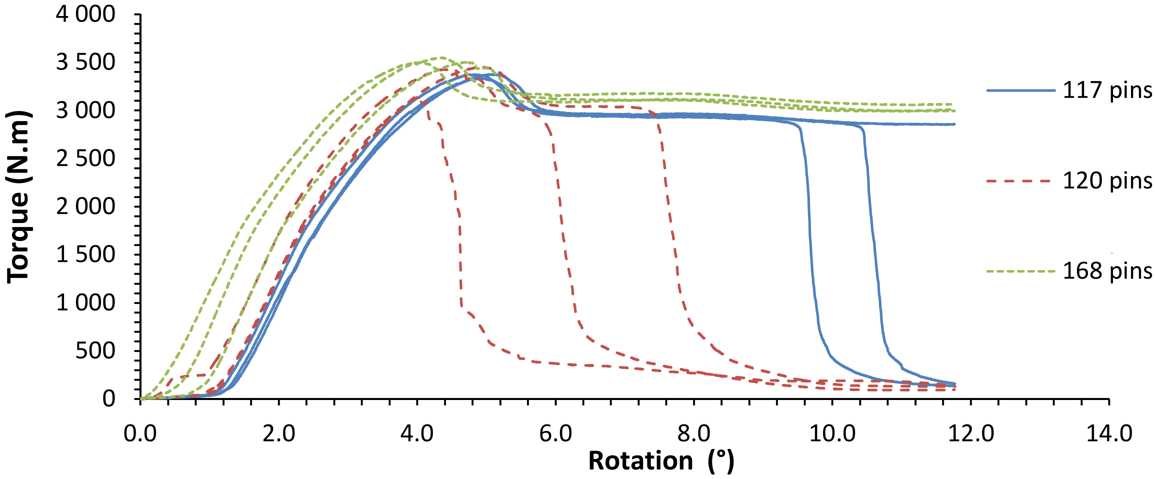

Figure 3. Experimental torque - rotation law of the assembly.

The following will lay the emphasis on the third configuration. Post rupture behaviour will not be studied in this article. A numerical and an analytical model of the interface are proposed and discussed.

3. Numerical model

3.1. Global model

The model, computed with LS Dyna R7.1, will focus on assembly's interface, only pins and composite part will be modelled. A cohesive layer is used to model the direct adhesion of the composite to the metal.

Other components are meshed with one integration point hexahedral elements. Mesh size goes from 0.1 mm on the pin to 0.3 mm on the rest of the interface.

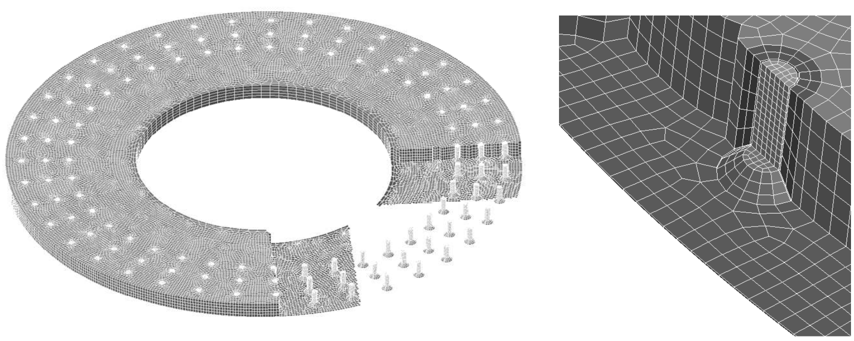

Figure 4. Interface numerical model: geometry and meshing

Characterization tests were performed to investigate each material behavior. Pin metal is represented with a classical elastic plastic law while the PA6 is represented with material law n°261 *MAT_LAMINATED_FRACTURE_DAIMLER_PINHO implemented in LS Dyna and developed by

Excerpt from ISBN 978-3-00-053387-7

Pinho and al [5]. This material law allows the user to implement the in-plane shear behavior with a defined curve. No data were given to implement the comportment law of cohesive elements. So the general law n°138 has been chosen and its parameters were calibrated on experimental results on double lap shear specimens (not described in this paper).

To avoid initial penetrations, a small gap of 0.025mm is left between the pin and the surrounding composite. A friction coefficient of 0.05 is added.

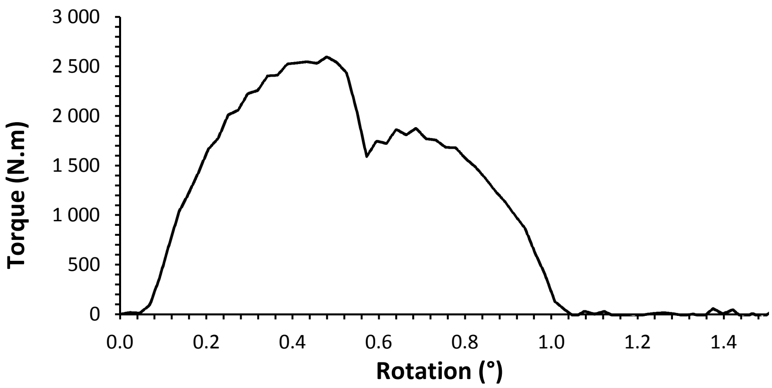

Figure 5. Numerical behaviour of the interface.

The major difficulty for this model is the scale difference between interface dimension and those of the pins that structure the interface. LS Dyna is a dynamic solver using explicit integration scheme, so the timestep is directly linked to the mesh size which penalize the model. To study this kind of textured interface, various studies explore multiscale approaches [6-12]. By refining the post processing it has been noticed, that a single force-displacement law, linking efforts at the base of the pin to its head's displacement, can be isolate for all the pins, in all the studied configurations. So an assumption has been made: the behaviour of a pin can be found from a numerical model at pin' scale. From this hypothesis, an analytical model giving the triangular specimen torsion law has been implemented.

3.2. Local model

Inside the interface model it has been noticed that a Representative Volume Element (RVE) can be isolated (Figure 6). Thanks to geometrical and loading symmetries according to the plan (x,y), only half of the RVE has been represented.

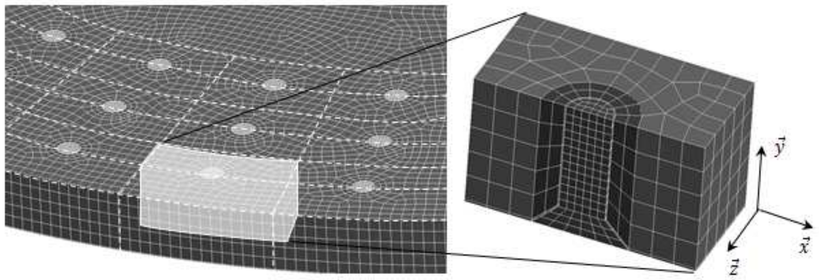

Figure 6. RVE Geometry and meshing

Excerpt from ISBN 978-3-00-053387-7

The same contact, material laws, and element types are used as in the DLS model. The bottom face of the geometry is fixed, and symmetry conditions are applied on the faces normal to x-direction. A constant speed, in the z direction is imposed on both faces normal to z. The comparison between RVE's behaviour and each pins row from each configuration is given in the following figure:

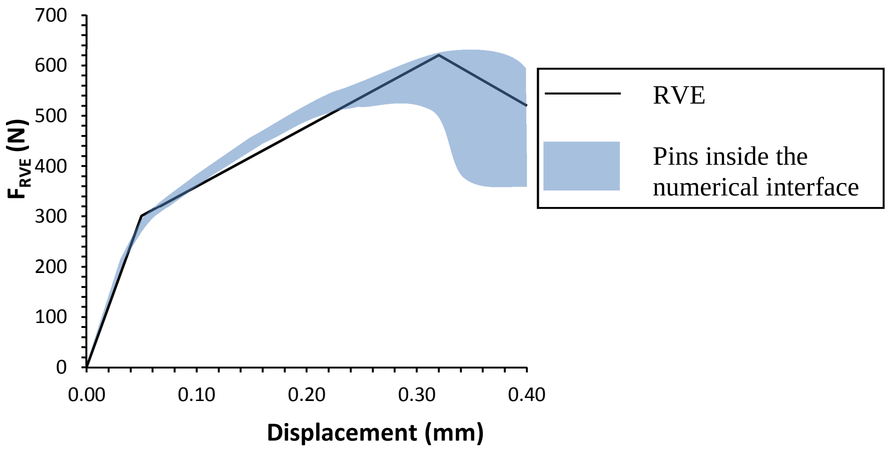

Figure 7. RVE effort displacement law.

This graph shows that the behaviour of the pin inside the RVE is representative of the behaviour of any pin inside the DLS. A bilinear flexion law is extracted from this graph. The rupture criterion which depends of the cohesive layer (i-e: metal to composite adhesion) is not associated to this law.

Now that the behaviour of one RVE has been isolated, an analytical algorithm giving interface comportment is proposed in the next part.

4. Analytical model

4.1. Algorithm construction

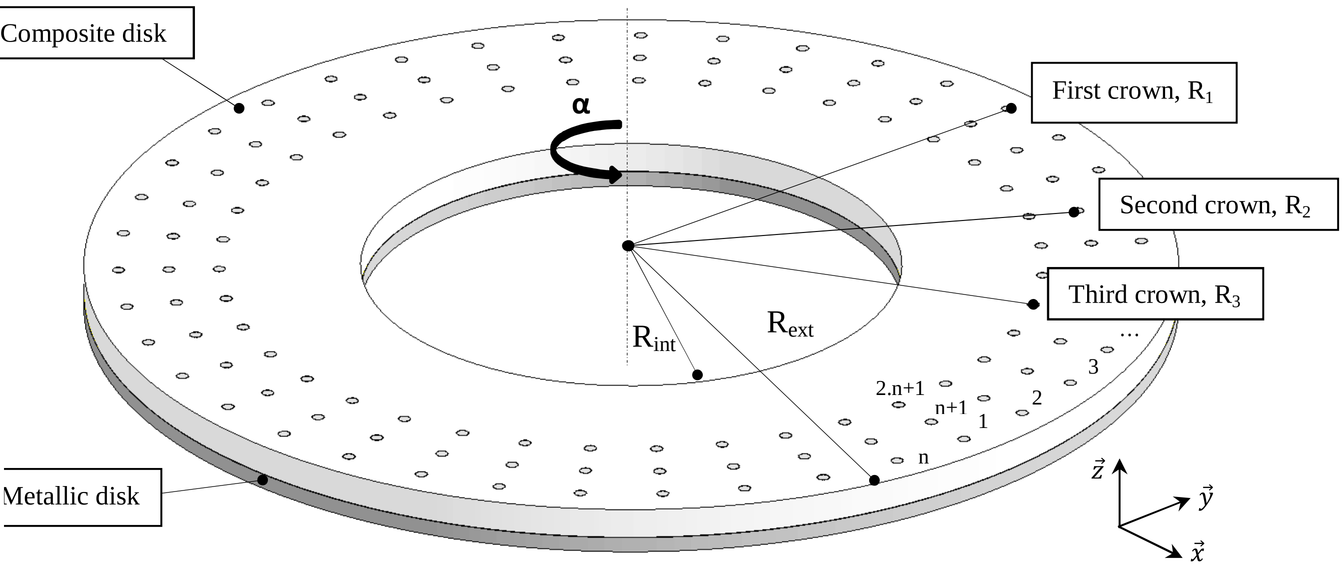

Figure 8. Analytical model: geometry and notation

An interface formed of m crowns of n pins each is considered. A rotation of an α angle is imposed on the exterior edge of the interface composite part. Resulting in an R.α displacement imposed on the exterior crown.

Pin's behaviour and cohesive layer on a RVE can be represented with a single multilinear, force displacement law $F_{RVE,i}$. Each pin displacement is noted u_i and corresponding excentricity is noted R_i.The resultant torque is the sum of all pins efforts, reported to disk center.

$$M_{tot} = \sum_{i=1}^{N_{pin}} R_i . F_{RVE}(u_i) \tag{1}$$

The problem is now to determine the displacements of each pin induced by the rotation. Displacements of the first n pins are already known from boundaries conditions.

Once equilibrium equations have been set up for each pin, the following linear equation system is obtained:

$$\bar{\bar{K}}.\bar{U} = \bar{F} \tag{2}$$

Where:

$$\bar{\bar{K}} = \begin{pmatrix} \left[A_n^{(2)}\right] & \left[B_n^{(2)}\right] & & & 0 \\ \left[B_n^{(2)}\right] & \left[A_n^{(3)}\right] & \left[B_n^{(3)}\right] & & \\ & \left[B_n^{(3)}\right] & \ddots & \ddots & \\ & & \ddots & \ddots & \left[B_n^{(m-1)}\right] \\ sym & & & \left[B_n^{(m-1)}\right] & \left[A_n^{(m)}\right] \end{pmatrix} ; \ \bar{U} = \begin{pmatrix} u_n^{(2)} \\ u_n^{(3)} \\ \\ u_n^{(m)} \end{pmatrix} ; \bar{F} = \begin{pmatrix} F_n^{(2)} \\ 0 \\ \\ 0 \end{pmatrix} \tag{3}$$

A tri-diagonal bloc system is now obtained where:

- $A_n^{(i)}$ is a n*n matrix representing the effort transmission between each pin of the i-th crown.
- $B_n^{(i)}$ is a n*n matrix representing the effort transmission between the i-th crown and the i+1-th crown.
- $u_n^{(i)}$ is a n vector representing the displacements of the n pin of the i-th crown.
- $F_n^{(2)}$ is a n vector representing the effort imposed by the displacement a the pin from the first crown to the rest of the system.

Slope variations of the F_{RVE} as described in Figure 7 can be take into account in the linear model, and the following behavior is obtained:

Excerpt from ISBN 978-3-00-053387-7

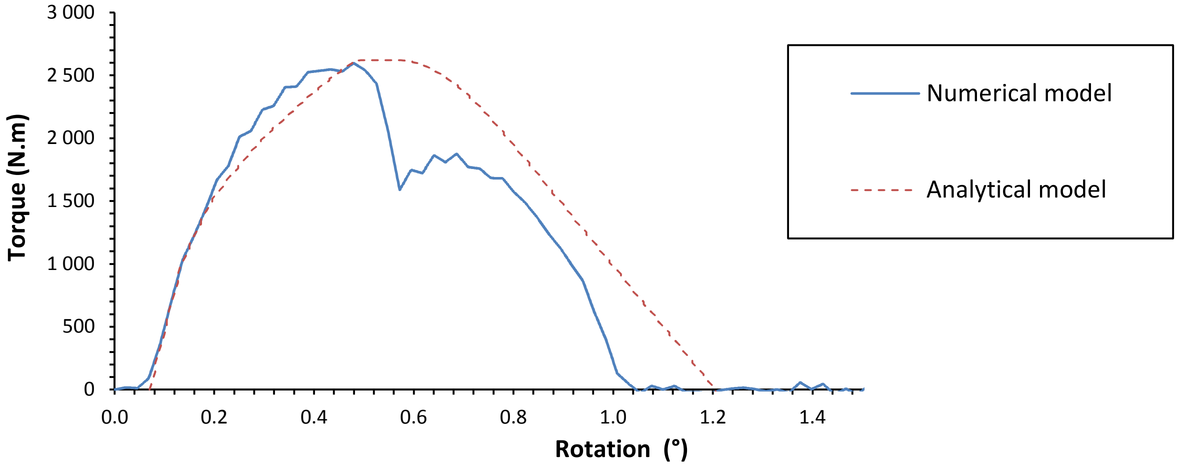

Figure 9. Comparison between numerical and analytical model (interface)

As demonstrate by the figure 1, the global behaviour is correctly represented by this analytical model.

4.2. Interface law

This torque rotation law can be inserted in the torsional law of a non linear spring, representing the interface. The full assembly (interface and overmolding) in now represented in a single solid element model.While the strengh of the assembly is well represented, the numerical model presents a stiffer answer to the solicitation than experimental result. This can be due to testbed stiffness. Indeed on a bonded configuration, the same difference between numerical and experimental stiffness have been reported. The imposed rotation is not well mastered in experimental case.

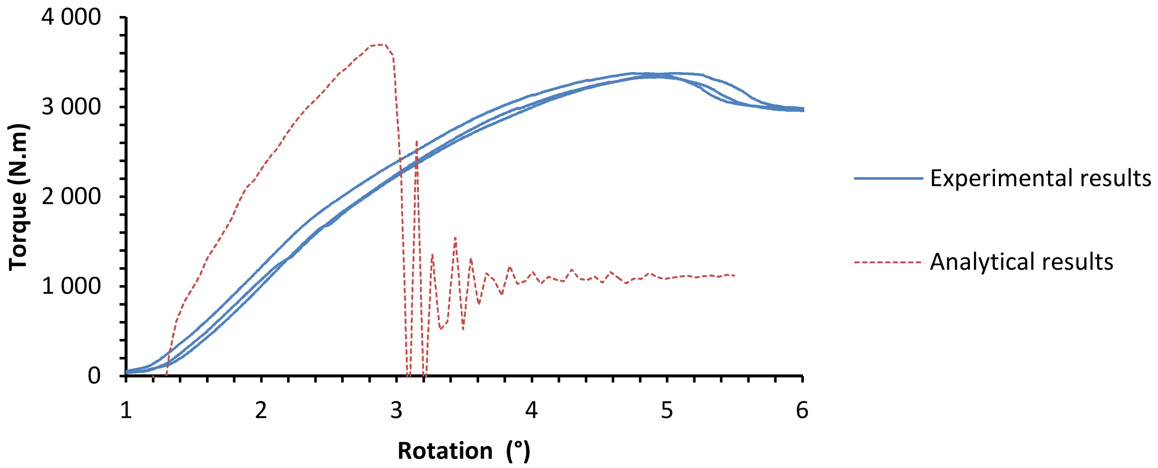

Figure 10. Comparison between experimental results and model result

4. Conclusion

The CMT pin technology is used to produce a multimaterial assembly between a steel part and a PA6, glass fiber thermoplastic composite. As a fine representation of the interface geometry would be complicate and expensive, a nonlinear rotational spring is proposed to simulate the global behavior of the interface. To implement spring parameters and find a method to study the local behavior of this assembly, a combination of a local numerical and an analytical multi scale models are proposed.
The local behavior of a RVE, a pin stamped in thermoplastic composite has been extracted. The flexural law obtained this way is then inserted in an analytical algorithm, which calculates the

Excerpt from ISBN 978-3-00-053387-7

comportment law of the interface under torsional loading. The whole interface can be then simulated with a simple nonlinear spring (whose parameters have been implemented from the previous algorithm) and inserted in another finite element model. The analytical algorithm works under any torsional solicitations. This method shows very fast results for a given pins disposition, torsionnal loading, and can be an important advantage for the pre dimensioning phases. The numerical model can be used if specific local post processing data are needed. This method represents a powerful tool for the comprehension and the development of the CMT pins assembly technology.
In future works an application to this method to a different texturing can be instigated. This method has also a high potential in optimization problems and can be used to find the ideal pins disposition answering interface specifications. Other kind of loading, as shear or out of plane loading could be studied with a similar approach.

Acknowledgments

This paper is part of the LIMECO project managed by IRT Jules Verne (French Institute in Research and Technology in Advanced Manufacturing Technologies for Composite, Metallic and Hybrid Structures). The authors wish to associate the industrial and academic partners of this project: Faurecia for leading the project, Compose Tools for designing and realizing the mold of the triangle shaped specimen and finally the Cetim for the torsion tests realized on the triangle geometry.

References

[1] J. Lotte & al. Smart multi material joint–hybrid joint of steel and FRP. *Proceedings of the Journées Européenes du Composite, Paris, France, 2015.*

[2] S. Ucsnik , Pin-based hybrid joining. *5th Anniversary of the Institute of Carbon Composite, Technische Universität, Munchen, Deutchland, 2014*

[3] S. Ucsnik & al, Composite to composite joint with lightweight metal reinforcement for enhanced damage tolerance. *Proceedings of the 16th European Conference on Composite Materials ECCM-16, 2014*

[4] S. Ucnsik & al, Experimental investigation of a novel hybrid metal-composite joining technology. *Composites : PartA,* 369-374, 2010

[5] S. T. Pinho & al, Physically based failure models and criteria for laminated fibre-reinforced composites with emphasis on fibre kinking. Part II: FE implementation . *Composites : PartA,* 766-777, 2006

[6] F. Bianchi & X. Zhang, Predicting mode-II delamination suppression in z-pinned laminates. *Composites Science and Technology,* 924-932, 2012

[7] F. Bianchi & X. Zhang, A cohesive zone model for predicting delamination suppression in z-pinned laminates. *Composites Science and Technology,* 1898-1907, 2011

[8] S. Heimbs, A. C. Nogueira & al, Failure behaviour of composite T-joints with novel metallic arrow-pin reinforcement. *Composites Structures,* 16-28, 2014

[9] N. Li & al, A micro-macro finite element model for failure prediction of ComeldTM joints. *Composites Science and Technology 117,* 334-341, 2015

[10] W. Tu & al, Multi-region mesh free method for Comeld™ joints. *Computational Materials Science 48,* 481-489, 2010

[11] W. Tu & al, Optimisation of the protrusion geometry in Comeld™ joints. *Composites Science and Technology 71,* 868-876, 2011

[12] H. Zhang & al, Study on the strength prediction model of Comeld composites joints. *Composites: Part B 43,* 3310-3317, 2012

Excerpt from ISBN 978-3-00-053387-7