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4-5 March 2013 MELBOURNE VIC

Conference Peer Reviewed Papers

Chief Editor

Dr. Rikard Heslehurst, UNSW (University College-ADFA)

The following papers presented at the Composites Australia and CRC-ACS, 2013 Composites Conference, held at Melbourne, Vic from Monday, 4th March through Tuesday, 5th March, 2013 have been peer reviewed.

3D weaving for large scale composite production on conventional narrow looms
Wendland, B. and Gries, T.
Institut für Textiltechnik of RWTH Aachen University (ITA)

Tailoring Laminate Bend-Twist Coupling Through Ply Position
L. J. Coutts-Smith, R. B. Heslehurst and W. F. Smith
School of Engineering and Information Technology, UNSW, Canberra

The Mechanical Properties of Epoxy Based Hybrid Biocomposites Reinforced with Harakeke and Hemp Fibres Tan Minh Le and K.L. Pickering
School of Engineering, the University of Waikato, Hamilton, New Zealand

Mechanical Performance of Modular GFRP Sandwich Assembly for Beam and Slab Construction
Sindu Satasivam, Yu Bai and Xiao-Ling Zhao
Department of Civil Engineering, Monash University, Clayton Australia

The Effect of Resin Additives on the Mechanical Properties of Vacuum Infused Composites
Rikard B. Heslehurst, PhD
School of Engineering and Information Technology, UNSW Canberra

Numerical Modelling of Glass Fibre Metal Laminates Subjected yo High Velocity Impact
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25th February 2013

NUMERICAL MODELLING OF GLASS FIBRE METAL LAMINATES SUBJECTED TO HIGH VELOCITY IMPACT

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Abstract

A finite element model is developed in this paper to simulate structural response of glass fibre metal laminates to high velocity impact loading using the commercial finite element analysis software LS-DYNA. The composite prepreg layers were governed by the material 22 (MAT_COMPOSITE_DAMAGE), while both Aluminium alloy sheets and copper bullets were modelled with the simplified Johnson-Cook material model. A non-linear cohesive contact was employed to simulate failure between adjacent layers, and an erosion contact to define contact between bullets and panels. The glass fibre prepeg layers are meshed using thin shell element named as THIN SHELL163 while aluminium sheets and the bullets with 3D solid element named as 3D SOLID 164. As an illustration, the developed finite element model is used to simulate the dynamic response of a flat GLARE sandwich panel to a projectile impact at velocity ranging from 152 m/s and 360 m/s. The relationship between initial velocities and exit velocities of the projectile during impact process obtained from numerical modelling agrees well with that obtained from experimental study, and this demonstrates the efficiency of the proposed finite element model.

Keywords: Fibre metal laminate, finite element, GLARE, high velocity impact,

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Introduction

Composite laminates such as fibre metal laminates (FML), have been widely used in space and aeronautical engineering structures. As a typical type of FML, glass fibre metal laminates (GLAREs) exhibit superior mechanical properties to the conventional lamina consisting of fibre-reinforced lamina or monolithic aluminium alloys only [1]. GLARE is widely used in the aviation industry [2-3], due to its superior material properties such as light weight, enhanced fracture toughness, and excellent fatigue and impact resistance.

The study of impact behaviour of FMLs has attracted significant research interests in recent years. Finite element modelling is a robust and versatile numerical tool for the analysis and modelling of engineering structures, especially for complicated structures under complex loadings. It has been used to model the impact performance of FMLs successfully and demonstrated to be a very effective method for investigation of the impact response of FMLs. A large number of studies on the numerical modelling of FMLs under projectile impact have been reported, but most of the previous research focused on low velocity impact behaviour [4-11].

For aerospace structures, high velocity impact is one of the typical extreme loadings which may occur in aerospace structure quite often. Several research on numerical modeling of FMLs under high velocity impact has been conducted. For example, to model the material properties of the aluminium layers in FMLs, the Johnson-Cook model or the simplified Johnson-Cook material model was selected as the material model to model aluminium alloy sheets under impact loading [12,13,14]. The Johnson-Cook material model can account for strain and temperature sensitive plasticity, and the simplified Johnson-Cook material model was employed if thermal effects and damage could be ignored to simplify computation [15].

For modelling fibre/epoxy prepregs in FMLs, the Chang and Chang Criteria based composite damage model was employed in [13] since this material model was able to simulate in-plane compressive, matrix cracking and fibre tensile failure. Yaghoubi and Liaw [12,13] modeled composite materials employing the composite model with Chang-Chang damage criteria [16,17] using LS-DYNA. Guida et al. [14] chosed the material card MAT8A in MSC.Dytran, which was a modified model [18] based on the Chang and Chang composite damage model. The flaw is this model is not capable of simulating 3D damage [19].

In this paper, a finite element model is developed for modelling high velocity impact response of FMLs. The developed model is used to model a flat GLARE panel with 4 layers of aluminium alloy sheets and three layers of glass fibre/epoxy prepregs subjected to high velocity impact (HVI) ranging from 152 m/s and 360 m/s. The commercial code LS-DYNA (Version 971) [13] is employed to conduct the finite element modelling. The aluminium alloy plies are modelled using the simplified Johnson-Cook Model, while the composite prepregs are modelled with Chang-Chang Criteria based MAT 22(MAT_COMPOSITE_DAMAGE). To strength the 3D damage simulation, the principal erosion strain and shear erosion strain is adopted. The relationship between initial velocities and exit velocities of the projectile during impact process is computed and agreement between the computed results with testing results [12] demonstrates the efficiency of the finite element model.

Geometry Models of a Beam-shaped GLARE Sandwich Panel and the Projectile

The flat GLARE sandwich panel includes three layers of unidirectional S2 glass fibre prepregs and 4 layers of Al 2024 T3 alloy sheets. Each layer of glass fibre prepregs is fabricated with four plies of unidirectional S2 glass fibre with the stacking sequence [0°/90°/90°/0°]. Thus the panel is stacked with 4 Al layers separated by each S2 glass prepreg. The projectile is a 0.22 calibre copper bullet. The rectangular GLARE panel is 152.4 mm in length, 25.4 mm in width and 2.744 mm in thickness. Each layer of glass fibre/epoxy prepregs and that of aluminium alloy sheets are 0.508 mm and 0.305 mm thick, respectively. The geometric models of the flat sandwich panel and the projectile, which are perpendicular to each other, are shown in Fig. 1.

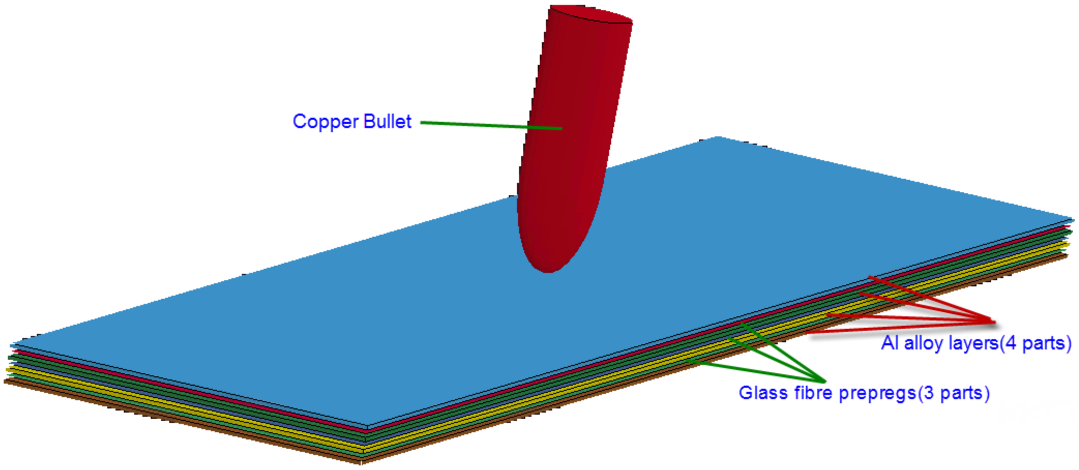

Fig. 1 Geometric model of the GLARE sandwich panel and the projectile

Finite Element Model

The copper bullet and the aluminium alloy sheets are meshed with 3D solid element named as Solid 164, while the three layers of unidirectional S2 glass fibre/epoxy prepregs with default Belytschko-Tsay thin shell element named as Thin Shell 163 in LS_DYNA using four integration points through thickness. The mesh density is 2.54 mm per element in the transverse direction while 2.5 mm per element in the longitudinal direction as shown in Fig. 2. Convergence test was conducted and this mesh density was determined to be the most appropriate since there is no variation in results comparing with those obtained from the mesh density of 1 mm per element in both the transverse direction and longitudinal direction with much less computation time.

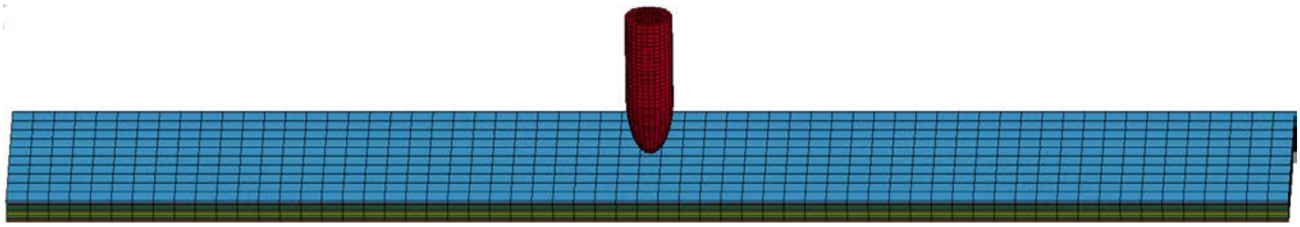

Fig. 2. The finite element model

MAT 22, an orthotropic material model based on Chang-Chang Criteria with optional brittle failure for composites, is adopted to model the unidirectional S2 glass fibre prepregs with material parameters shown in Table 1. The aluminium alloy layers and the copper bullet are modelled using the simplified Johnson–Cook material model [9], in which thermal effects and damage are not considered. Corresponding material parameters for Al 2024 T3 sheets and copper projectile are listed in Table 2. Since erosion has not been accounted for in the two constitutive models, the MAT_ADD_EROSION option is used along with the material models to model erosion during impact. The strain failure criterion is employed for element deletion. Since MAT_22 is not a rate-sensitive model, 0.936 was used for the value of both principal and shear erosion strain [10] to improve correlation at higher impact velocities. Nodes in both left sharp end and right sharp end of the panel (see Fig. 2) are fully fixed in the model as boundary conditions.

Table 1: Parameters for unidirectional S2 glass fibre/epoxy[12]

Density (kg/m^3)	Poisson's ratio			Young's modulus(GPa)			Shear Modulous(GPa)		
	PRBA(ν_{21})	PRCA(ν_{31})	PRCB(ν_{32})	EA	EB	EC	GAB	GBC	GCA
2×10^3	0.0575	0.0575	0.33	54	9.4	9.4	5.6	5.6	5.6

Shear strength (SC, MPa)	Longitudinal tensile strength (XT, MPa)	Transverse tensile strength (YT, MPa)	Transverse compressive strength (YC, MPa)	Ultimate strain (%)
76	1900	57	285	3.5

Table 2: Parameteres for AA 2024 T3 sheets and copper projectile

	Density (ρ, kg/m^3)	Poisson's ratio(ν)	Young's modulus (E, GPa)	Static yield limit(A, MPa)	Strain hardening modulus (B,MPa)	Strain hardening exponent(n)	Strain rate coefficient (C)
AA 2024[20]	2770	0.33	73.084	369	684	0.73	0.0083
Copper[21]	-	0.33	117.21	4.36	457.81	0.37575	0

Two kinds of contact are introduced in this model. One is the contact between the projectile and other parts of the sandwich panel via setting the option CONTACT_ERODING_SURFACE_TO_SURFACE in LS-DYNA. Another option, CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK, is chosen to define the mutual contact between aluminium alloy sheets and unidirectional S2 glass fibre prepregs, specifically for delamination and debonding. Also, delamination and debonding between the layers were assumed to be governed by the criterion [8]:

$$\left[\frac{\sigma_n}{NFLS}\right]^2+\left[\frac{\sigma_s}{SFLS}\right]^2\geq 1$$

Where: σ_n and σ_s are normal and shear stresses on the layer interface, respectively

NFLS and SFLS are normal and shear strengths of the interface.

Shear failure is assumed to be mainly responsible for delamination and debonding. NFLS is set to a value as high as 2 x 10^5 GPa. As a consequence, delamination and debonding are governed by SFLS with a value of 0.1 GPa in the model.

Numerical Validation

To validate the finite element model, finite element analysis of the flat GLARE sandwich composite panel is conducted in LS-DYNA by employing the finite element model. The initial impact velocity ranges from 162 m/s to 360 m/s, and the residual velocity of the projectile after impact is computed. The relationship between the impact velocity and exit velocity of the projectile obtained from numerical modelling is shown in Fig. 3 and compared with those from experimental study [12]. It can be seen that the numerical results agree well with the test results which demonstrates the efficiency of the developed finite element model in the modelling of the high velocity impact behaviour of FMLs.

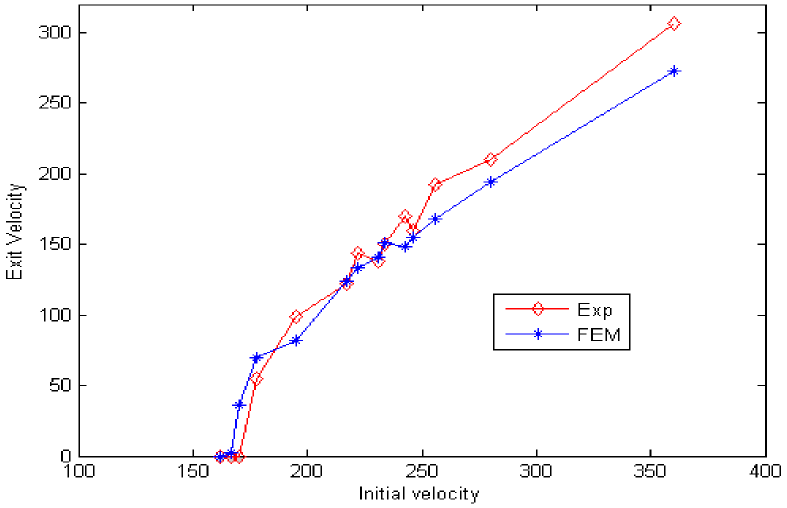

Fig.3 Relationship between initial impact velocity and exit velocity of the projectile

At approximately 160 m/s both the model and experiment show that there is no penetration. At a slightly higher velocity (around 165 m/s) the model shows penetration whilst none is seen in the experiment. The model is less accurate in predicting the transition region (between penetration and no penetration of the GLARE panels). But overall, when significant penetration occurs the model agrees very well with the test data.

Fig. 4 shows the change of global kinetic energy, internal energy and total energy. The total energy slightly increased. The decrease of kinetic energy mainly accounts for the rise of internal energy.

The impact process of the GLARE composite at the impact velocity of 217 m/s obtained from numerical simulation is shown in Fig. 5 with the Von Mises stress contour plotted. Though no experimental result is available for comparison, the simulation predicts a very reasonable development of deformation and damage of the FML panel and the bullet during the impact process.

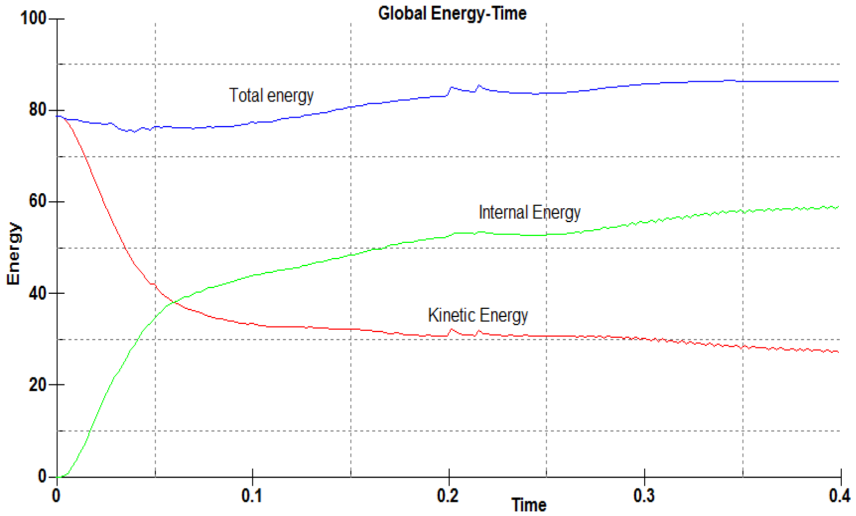

Fig. 4 Global kinetic energy, internal energy and total energy

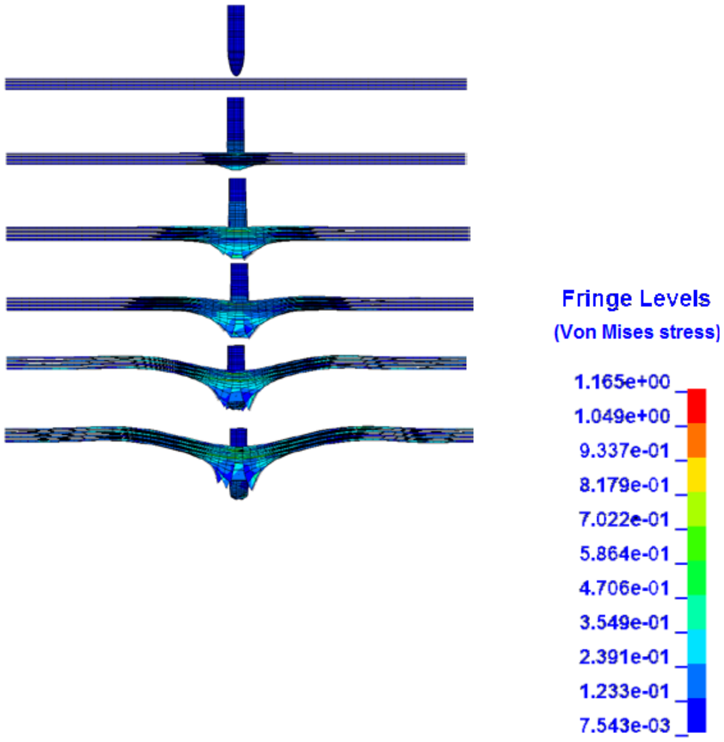

Fig. 5 Impact process of the GLARE composite at the impact velocity of 217 m/s

Summary and Conclusions

A finite element model is developed in this paper to model the high velocity impact response of glass fibre metal laminates. The material model with Chang–Chang damage criteria is employed for the composite prepreg layers. The simplified Johnson-Cook material model is adopted to model both aluminium alloy sheets and copper bullets. The option CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK is employed to define contact between adjacent layers, and CONTACT_ERODING_SURFACE_TO_SURFACE to define contact between bullets and panels. The developed finite element is used to model the high velocity impact response of a flat GLARE sandwich panel, and the agreement of the computed results with the test results demonstrates the efficiency of the developed finite element model.

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