Prediction of the ballistic limit of an aluminium sandwich panel

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Prediction of the ballistic limit of an aluminium sandwich panel

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Abstract. This paper presents research on modelling the impact of a 150g projectile on a 35mm thick aluminium sandwich panel. The objective of the work is a predictive modelling capability for the ballistic limit of the panel. A predictive modelling capability supports the design of capture and deorbit missions for large items of space debris such as satellites and rocket upper stages. A detailed explicit finite element model was built using the LSDYNA software and results were compared with experimental data for the projectile exit velocity to establish key parameters. The primary parameters influencing the model behaviour were the strength and failure of the aluminium face sheets and the friction between projectile and panel. The model results showed good agreement with experimental results for ogive nose projectiles, but overestimated the exit velocity for flat nose projectiles.

1. Introduction

The level of debris in Earth orbit is now significant and it is now necessary to reduce the debris population. A proportion of this debris consists of large items including discarded rocket upper stages and derelict satellites. To remove these large items it is proposed to launch a satellite to rendezvous with the debris, then capture and then deorbit in a controlled manner, a concept known as active debris removal [1]. Different methods for capturing derelict satellites have been proposed, with one concept based on the use of a harpoon.

The objective of this work is the development and validation of a modelling method to predict the ballistic limit of representative sandwich panels. Good knowledge of the ballistic limit is required for the harpoon capture concept, as the harpoon must penetrate the structure but must not cause significant additional damage or generate debris. Experimental data from a series of tests performed at the University of Cambridge [2] was available for comparison and the LSDYNA explicit finite element code was used to simulate the impacts.

2. Stiffened panel model

The experimental panels consisted of two 1.27mm thick aluminium 2024-T81 sheets, bonded to an aluminium honeycomb core, for a total panel thickness of 35mm. Each panel was drilled with four 6.5mm holes in the corners, on a 105mm pitch. Steel studding, passing through the panel holes, was used to hold the panel to the target support, with aluminium washers in direct contact with the panels [2]. In the experiments, 20mm diameter 150g steel projectiles with different nose shapes were fired at target panels. In this work we investigate the ogive nose and flat nose projectiles, for both normal impact and 45° impact angles.

Following previous experience with modelling the ballistic limit of aluminium plates [3] a detailed modelling approach was taken where the face sheets were meshed using solid elements (5 elements through thickness) and the honeycomb core geometry was directly modelled using shell elements. Element erosion is used to represent material failure and the projectile and supports are treated as rigid. The models for the normal and 45° impact cases are shown in figure 1. The material properties for the face sheets were derived from the typical stress strain curve for 2024-T81 alloy published in MIL-HDBK-5 [4], and the properties for the honeycomb material were based on published data for the strength of 5056 aluminum foil [5]. To verify the sheet material properties a standard tension test was modelled using solid element s of equivalent size to the face sheet model. Figure 2 shows the stress-strain curve measured from a tension test model, figure 3, overlaid on the MIL-HDBK-5 curve showing good agreement for the resultant behavior from a finite element model

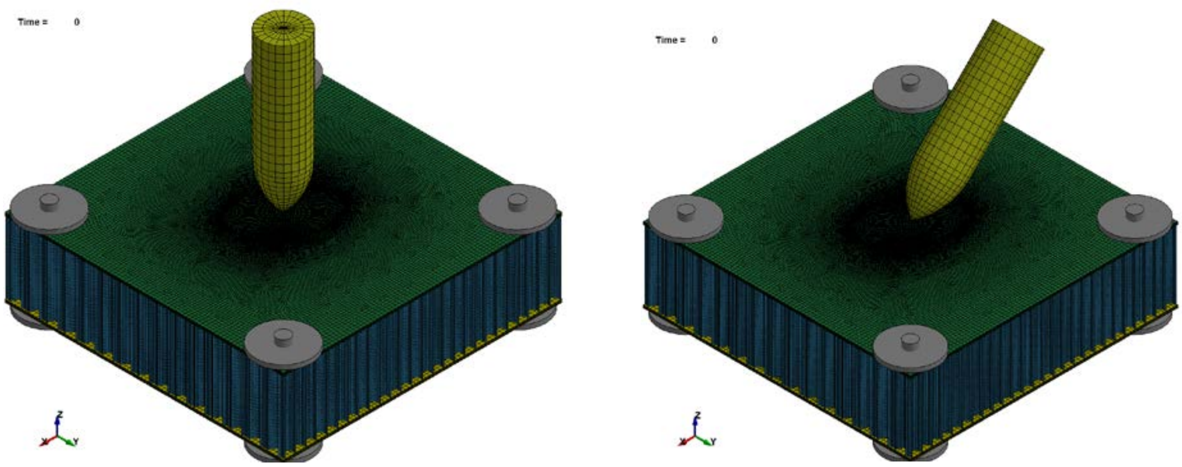

Figure 1: Finite element panel model for 0º impacts (left) and 45º impact (right). The rear face sheet mesh differs between the two models due to the different projectile exit location.

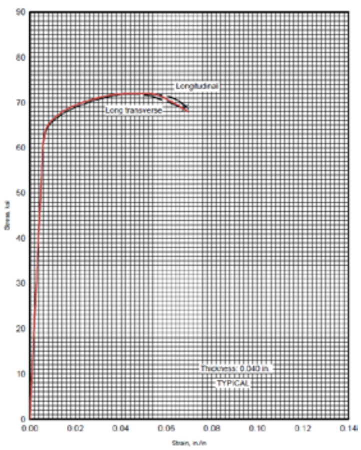

Figure 2: Stress vs strain from FE tension test model (red line) overlaid on MIL-HDBK-5 curve [4].

Figure 3: Initial (top) and final(bottom) view of FE tension test model used to check material stress-strain curve. Fringes of effective plastic strain.

A 70m/s impact of the ogive nose projectile was selected as the test case for sensitivity studies to investigate the influence of the sheet and honeycomb models, projectile-panel friction and the core to sheet bond strength. The friction coefficient was selected to match the experimental exit velocity.

3. Model results

For the ogive nose projectile, six analyses were run for impact velocities from 44 m/s to 98 m/s, with the only difference between each analysis being the initial velocity of the projectile. The results showed strong agreement with the experimental projectile exit velocities over the whole range of velocities considered. Figure 4 shows the comparison between the model results for the projectile exit velocity and the constant energy loss fit to the experimental results. Figure 5 shows a sequence of model results for the 70m/s analysis, illustrating the progress of the projectile penetration. Compared with the experimental results, the deformation of the rear sheet is under-predicted in the models. Analyses were also run for the 45º impact experiments, and also gave good agreement with the experimental results, including the deflection of the projectile by the rear sheet at lower impact velocities.

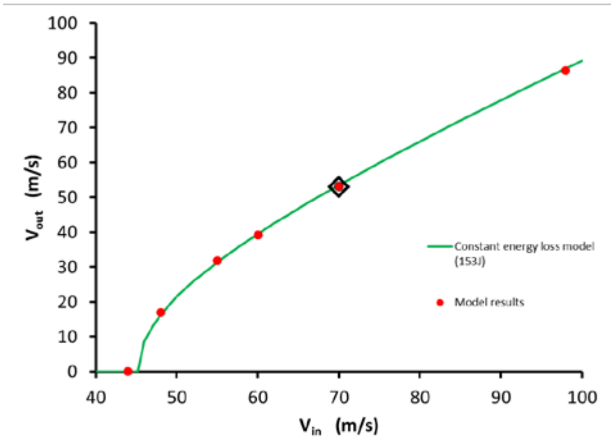

Figure 4: Comparison of numerical residual velocities with the constant penetration energy fit to the experimental results. The black diamond indicated the velocity where sensitivity studies were used to match the experimental velocity.

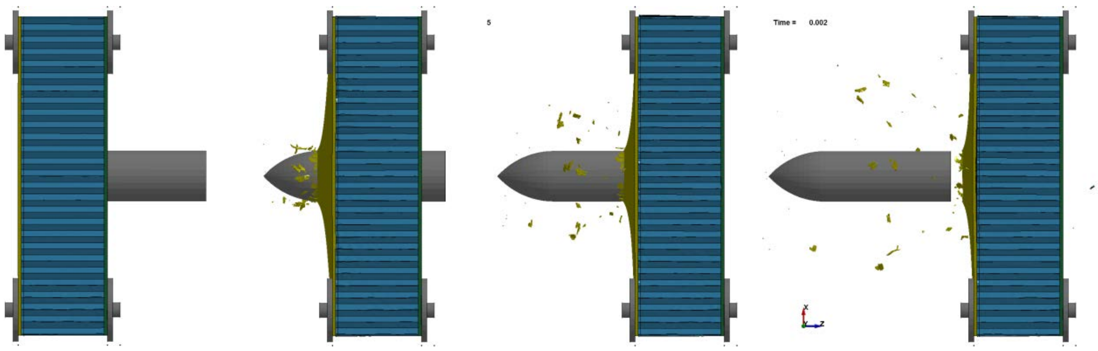

Figure 5: Side view of 70 m/s impact model, images at 0.5ms, 1.0ms, 1.5ms and 2.0ms.

For the flat nose projectile analyses with impact velocities of 90m/s and 74m/s were run, with all model settings otherwise identical to the ogive nose projectile analyses. The results from these are presented in figure 6, and show that the model significantly over predicts the exit velocity in both cases, although the model correctly predicts the failure modes of the front sheet (plugging) and the tearing of the rear face sheet, figure 7. From the experimental results it is clear that crushing of the honeycomb core is an important mechanism in these impacts and one that is not properly captured in the model. This is consistent with the under-prediction of the absorbed energy, as crushing of the core is not a significant mechanism for the ogive nose projectiles.

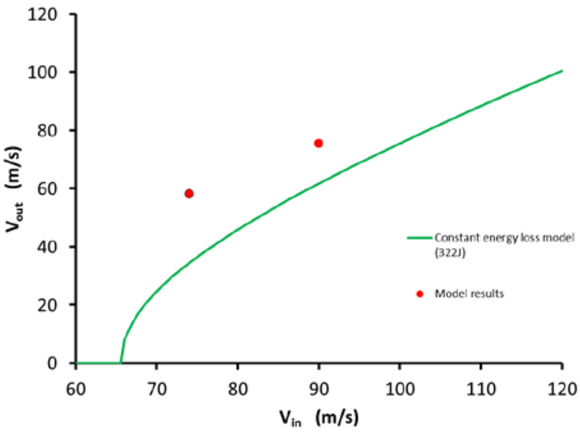

Figure 6: Residual velocity from 0º panel analyses for a flat nose projectile compared against experimental results.

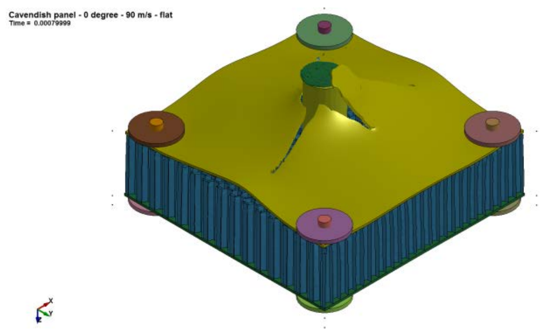

Figure 7: View of 90m/s flat nose impact analysis showing rear face sheet deformation as the projectile begins to exit the panel.

4. Conclusions

A detailed explicit finite element model of an aluminium sandwich panel has been developed. For the impact of an ogive nose projectile this model has shown excellent agreement with experimental data, including the ability to match the ballistic limit of the panel. For a flat nose projectile the model over predicts the exit velocity, as the crushing of the honeycomb core is not correctly captured. Future work will include experimental tests on the sheet material to reduce the uncertainty in material properties and investigation of how the core crush behaviour seen in the flat nose projectile impacts can be correctly modelled.

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References
[1] Innocenti L, Soares T, Delaval J, ESA Clean Space Initiative. *In: Proc. of 6th European Conf. on Space Debris*, ESA SP-723, 2013.
[2] Taylor NE, Jardine AP Panel penetration experiments. *University of Cambridge*, August 2015.
[3] De Vuyst T, Vignjevic R, Azorin Albero A, Hughes K, Campbell JC, Djordjevic N A study of the ballistic limit of AA2024-T351 sheets impacted by spherical and cubical steel projectiles. *Submitted to: ASME Journal of Applied Mechanics*, January 2016.
[4] Military Handbook: Metallic materials and elements for aerospace vehicle structures. MIL-HDBK-5H. United States Department of Defense, December 1998.
[5] Aluminum Standards and Data, The Aluminum Association Inc., Washington DC, 1997