VELOCITY ATTENUATION AND FORCE TRANSFER IN FOAM-FILLED LAYERED CLADDINGS SUBJECTED TO BLAST AND IMPACT

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Summary The mechanism of air blast attenuation in foam-filled single- and double-layer sacrificial claddings is examined applying an analytical and numerical analysis. It is demonstrated that a reduction of the total thickness of the cladding without increasing the force transferred to the main structure can be achieved by placing a higher density foam layer near to the loaded end while a lower density foam layer is preferable near to the stationary end of the cladding.

INTRODUCTION

The aim of this study is to examine the air blast attenuation in finite thickness cladding structures with equal masses and comprising single or double layers of different foam materials, which exhibit strain hardening. Particular attention is paid to the mechanism of compaction and to the stress variations at the stationary end of the claddings which determine the force transmitted to the main structure. An approach, which is based on the actual stress-strain characteristic of a cellular material [1], was used to clarify the mechanism of compaction and to obtain more realistic estimates for the energy absorption capacity of foam materials. It was shown that the degree of compaction is velocity dependent moreover, the strains within the compacted regions are not uniform. Therefore, the assumption of a pre-defined densification strain [2,3] usually leads to an overestimation of the absorbed energy due a blast or impact.

DOUBLE-LAYER FOAM CLADDING

A double-layer cladding made of foam materials with different densities is schematically shown in Fig. 1. The deformation of the constituent layers are calculated from the displacement of the cover plate, u_1, and displacement u_2 of the interface between the foam parts. For the particular purposes of the current analysis, it is anticipated that the density of the front layer, ρ_{01}, is larger than the density of the rear layer, ρ_{02} (Cymat foam with ρ_{01} = 570 kg/m^3 and ρ_{02} = 253 kg/m^3 are considered). The equations of motion of a double-layer cladding with respect to the displacement u_1 and thickness of the compacted zone of the front layer, h_1, during the time interval $0 \le t \le t_1$ (t_1 is the time for the propagation of the primary compaction wave in the front foam layer with thickness L_1) are obtained as

$$\frac{dh_1}{dt} = G([\varepsilon_1(V_1 - V_2)]) - (V_1 - V_2),\ G_1(\varepsilon_1) = (V_1 - V_2)/[\varepsilon_1], \tag{1a}$$

$$\frac{dV_1}{dt} = -\left[\sigma_{Y1} + \rho_{01}\frac{(V_1 - V_2)^2}{[\varepsilon(V_1 - V_2)]} - \rho_{01}\left(\frac{V_1 V_2 + V_2^2/2}{[\varepsilon_1(V_1 - V_2)]}\right)\right]\frac{1}{\{m_1 + \rho_{01}(u_1 + h_1 - u_2)\}} \tag{1b}$$

$$\frac{dV_2}{dt} = -\left[\sigma_{Y2} + \rho_{02}\frac{V_2^2}{[\varepsilon_2(V_2)]} - \sigma_{Y1}\right]\frac{1}{\{m_2 + \rho_{01}[L_1 - (u_1 + h_1 - u_2)]\}}, \qquad \frac{du_1}{dt} = V_1(t), \qquad \frac{du_2}{dt} = V_2(t). \tag{1c-e}$$

In the above equation, σ_{Y1} and σ_{Y2} are the yield stresses of the materials in the front and rear foam layer, respectively, m_1 is mass per unit area of the cover plate and m_2 is the mass per unit area of the compacted region behind the wave front in the rear foam layer; G_1 is the speed of the compaction wave in the front layer. Equations (1a-e) are solved numerically with initial conditions

$$V_1(0) = V_0, \quad V_2(0) = 0, \quad h_1(0) = 0, \quad u_1(0) = 0, \quad u_2(0) = 0. \tag{2a-e}$$

During the time interval $t_1 < t \le t_2$ the compaction wave propagates through the rear foam layer and reaches the stationary end of the cladding at $t = t_2$. The compacted front layer with initial length L_1 and initial density ρ_{01} continues to move as a rigid body therefore $V_1(t) = V_2(t)$ and the equations of motion of the cladding become

$$\frac{dV_2}{dt} = -\left[\sigma_{Y2} + \rho_{02}\frac{V_2^2}{[\varepsilon_2(V_2)]}\right]\frac{1}{\{m_2 + \rho_{02}(u_2 + h_2)\}}, \quad \frac{dh_2}{dt} = G_2([\varepsilon_2(V_2)]) - V_2(t),\ G_2(\varepsilon) = [V_2]/[\varepsilon_2], \quad \frac{du_2}{dt} = V_2(t) \tag{3a-d}$$

where h_2 is the length of the compacted region of the foam behind the wave front in the rear layer, G_2 is the wave propagation speed. Equations (3a-d) are solved numerically with initial conditions

$$V_2(t_1) = V_1(t_1), \quad h_2(t_1) = 0, \quad u_2(t_1) = \bar{u}_2 \tag{4a-c}$$

where $\bar{u}_2$ is the values obtained at $t = t_1$ according to Eqs (1a-d).

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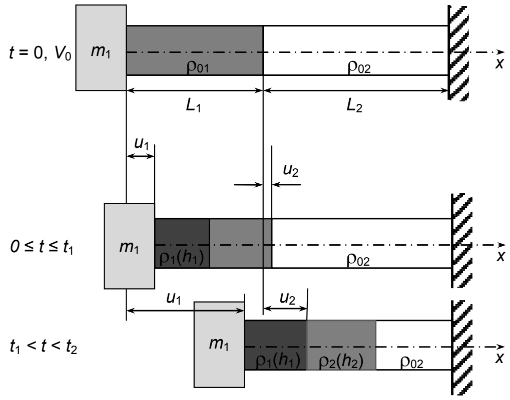

Fig. 1 Schematic of a double-layer cladding.

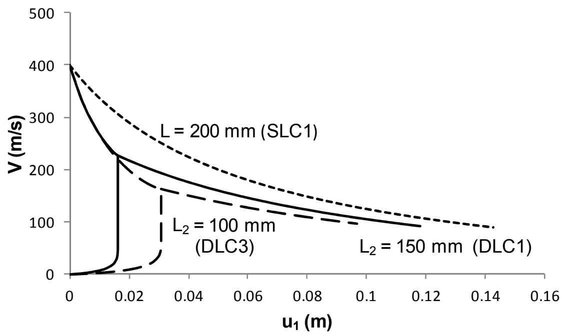

Fig. 2 Velocity attenuation in claddings with different configurations, $V_0 = 400$ m/s.

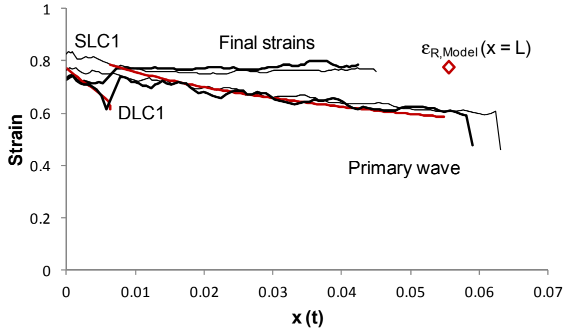

Fig. 3 Strain distribution within the primary compaction wave in DLC1 ($L_1 = 22.2$ mm, $L_2 = 150$ mm), $V_0 = 400$ m/s.

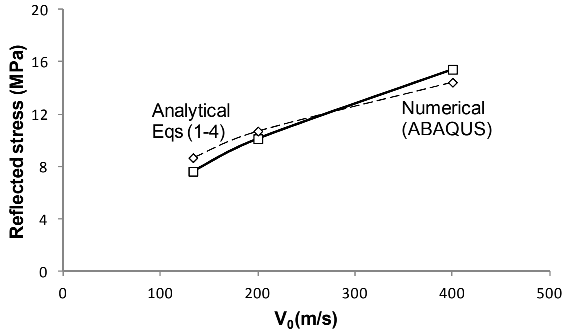

Fig. 4 Reflected stress, claddind DLC1, blast loading per unit area: 6280 Ns/m^2.

EQUIVALENT MASS CLADDINGS

The response of equivalent mass claddings with different density layers to a blast loading is studied and some representative results are shown in Figs 2 – 4. It is obtained that the desired velocity attenuation during the propagation of the primary compaction wave can be achieved by varying the thicknesses of the constituent layers as shown in Fig. 2 for double-layer claddings (DLC1, DLC3) with a 2mm thick cover plate. A comparison is presented with the corresponding velocity attenuation in a single-layer cladding SLC1 ($\rho_0 = 253$ kg/m^3 , $L = 200$ mm).

It is shown that the final compaction strains result from multiple wave reflections from the moving and stationary end therefore the final strains are generally larger than those within the primary compaction wave as shown in Fig. 3 (the thicker curves correspond to the results for double-layer claddings while the thinner curves represent the results for the single-layer cladding SLC1). Nevertheless, the first reflection of the compaction wave from the stationary end gives the major contribution to the stress transmitted to the main structure. The strain values predicted by the proposed analytical model are also shown in this figure. The predicted stresses reflected from the stationary end are shown in Fig. 4.

CONCLUSIONS

The present analytical approach allows for a further explication of the compaction mechanism of the foam layers in sacrificial claddings. It was established that the blast energy is absorbed by the cladding core as a result of multiple reflections of the compaction wave. The unique relationship between the strains and stresses allowed determining the strains and stresses at the stationary end of the cladding within the reflected compaction wave. It was obtained that among the equal mass claddings, those with lower density transfer lower stresses to the stationary end. The use of double-layer claddings comprising foam layers with different densities is discussed. It was shown that a reduction of the total thickness of the cladding without increasing the force transferred to the main structure can be achieved by placing higher density foam near to the loaded end while lower density foam is preferable near to the stationary end of the cladding. It was noticed however, that the reduction of the thickness of the lower density foam invokes a larger number of reflections from the stationary end, which can cause a significant increase of the stress at the stationary end.

References

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