NON-UNIFORM MATERIALS BEHAVIOR IN MULTI-LAYERED COMPOSITE STRUCTURE UNDER BLAST WAVE

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Introduction

Blast wave caused by an explosion is a phenomenon associated with potential threat to structures [1]. Types of protective single plate were initially developed for structural safety [2]. Most of the single layer protections were made by heavy metals, and hence led to an increase of weight. As the case stands, multi-layered composite structures have been considered for the effective applications in structural safety by means of enhanced energy absorption performance with lightweight [3].

In this work, a numerical analysis with explosion test was performed to predict the impact absorption performance coupled with the deformation behavior of the materials for multi-layered composite structures.

Experimental

Several types of materials such as aluminum alloy, aluminum-foam, rubber and polymer matrix composites (PMCs) were employed for the analysis. Aluminum alloy and aluminum foam were particularly selected for the excellent energy absorption characteristics with a good ductility and formability. Structures having an internal porosity can successfully absorb the impact energy upon blasting load. Usually rubber shows hyper-elastic behavior that is also connected with energy absorption properties. Multi-layered structure was made according to the combination of these materials. The remaining shape of the structure was finally built of PMCs due to the high strength and stiffness.

The order of stacking sequence and thickness of each layer were followed by the previous work [4]. The size of specimen was 1,000 x 1,000 mm^2 and had a different thickness of each material. Table 1 shows the summary of material data used in the analysis.

Specimen was peripherally clamped with square steel frames. A 0.5 kg C4 charge was located at 500 mm distance from the specimen. Four acceleration sensors were set up and measured the subsequent data. The results were then compared with finite element analysis.

Finite Element Analysis

Numerical simulations were conducted by using LS-DYNA 971 software. The arbitrary Lagrangian Eulerian (ALE) method was employed in the computation, so as to the air space with explosive charge was modeled by Lagrange scheme and the structure was modeled by Eulerian. Models were built in 1/4 symmetry shape to reduce the computation time.

The structure was constrained by the jig which has 113 mm width as shown in figure. The stress variations at each layer and the distributions of deformation behaviors were predicted. Fig. 1 shows the FE model for the structure with the positions for the analysis.

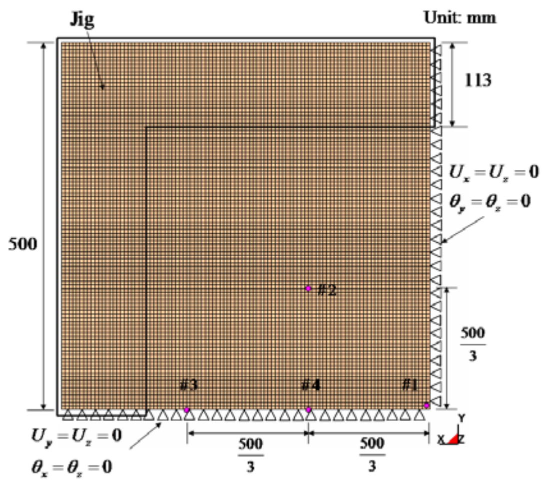

Fig. 1 Finite element model for the multi-layered structure. The number indicates the positions for the analysis of deformation characteristics.

Table 1 Summary of material data used in finite element analysis

Layer No.	Material (LS-DYNA model No.)	Density (g/cc)	Elastic or shear modulus (GPa)	Strength (GPa) (failure strain, %)	Thickness (mm)
1	Aluminum (Mat 13)	2.70**	G=28.19**	0.480** (7.0)**	12.7
2	Al-foam (Mat 63)	0.449*	E=0.631*	0.00133* (5.0)*	15
3	Rubber (Mat 7)	1.20*	G=1.361*	-	3
4	PMCs (Mat 162)	1.85**	Ex=Ey=271.1**, Ez=12** Gxy=2.9**, Gyz=Gzx=2.14**	0.604(tensile) ** 0.291(compressive) **	12.7

* Experimental data obtained from current work, and ** referred from [5,6]

Table 2 The maximum accelerations, deflections and effective stress at the positions as indicated in Fig. 1

No.	Exp.	Predicted		
	Acc. (G)	Acc. (G)	Deflection (mm)	Effective stress (MPa)
# 1	6750	6016	5.02	35.88
# 2	6461	5303	3.95	27.88
# 3	7108	5886	1.8	15.50
# 4	7062	5715	4.5	24.17

Results and Discussion

Table 2 shows the experimentally measured maximum acceleration together with the predicted values. As shown in the results, spatial distributions of all data occurred upon the blasting impact. The difference between the measured and predicted of the maximum acceleration particularly was less than 20 %. Fig. 2 shows the predicted stress variations at the positions as impact time goes by. As can be seen, the time corresponding to the peak stresses at all positions are approximately the same whereas the shock wave front did not impact the structure at the same time. This phenomenon represents that the stress wave inside the structure spreads out evenly during the propagation. Fig. 3 shows the predicted stress variations at the front center of individual layer and the same position of backside of multi-layered structure. As shown in the graph, the stresses changed very rapidly within 1 millisecond for the peak stress.

Conclusion

The level of stress at both front (i.e., aluminum layer) and backside of multi-layered structure was significantly higher than that of other layers because the propagated and reflected stress waves in the structure were coupled at the front and rear of the structure. High frequency of stress variation at the front layer occurred during the process than that of other layers because the transition of stress wave between interfaces of materials is not easy.

Since the first position is the nearest blasting impact, both the deflection and effective stress at the position

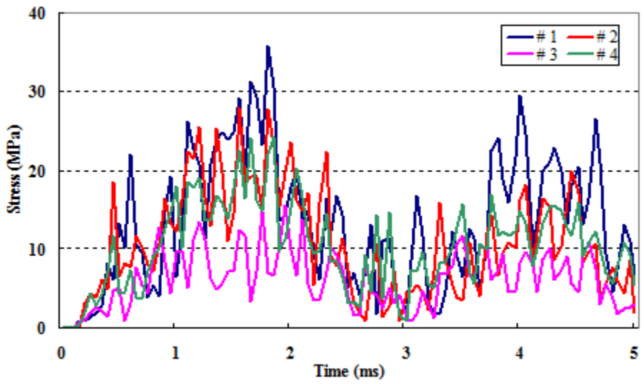

Fig. 2 Stress variations at each position on backside of multi-layered structure.

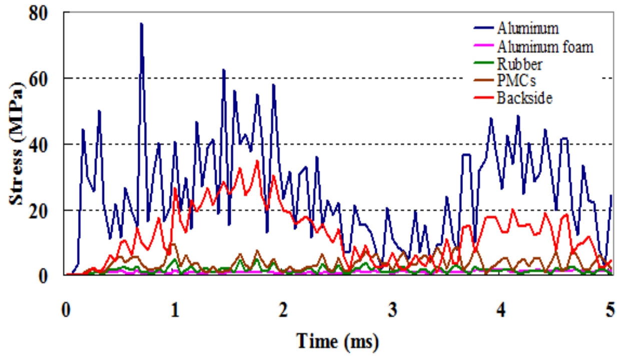

Fig. 3 Stress variations at each layers and backside of multi-layered structure.

were larger than those of other positions while the time corresponding to the peak stresses at all positions are approximately equal. By the consideration of the rear layer (i.e., PMCs), the level of stress at the front area was lower than that of the back part. It means the stress wave have a much effect on backside than that of inside resulting in the material failure such as scab on the back of structure.

The reduction of thickness of aluminum foam was larger than that of other layers while the stress level of aluminum foam was the smallest. The aluminum foam thus can sufficiently absorb the shock energy in the structure.

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