A Study on Improvement of Laminate Structures Subjected to Low-Velocity Impact

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Introduction

FRP laminated structures have advantages of light mass and high strength, but the impact strength are always lower because of its form types. In this study, the constrained layered damping (CLD) has been utilized for raise the impact strength of FRP laminated structures.

The common fractures of laminated components are fiber crack and delamination. Constrained layered damping (CLD) is combined with thin metal and viscoelastic glue. The property of CLD is dissipating the dynamic loading energy by shear deformation. In this study, the CLD is adhered to the back of laminate specimens and used to absorb the low-velocity impact energy. Finally, the efficiency of CLD used to ease the delamination and improve the post-failure strength of laminate components is confirmed.

Method

Both dynamic impact experiments and quasi-static simulation have been considered to estimate the improvement of laminate plates and shells subjected to low-velocity impact.

About low-velocity impact experiments, laminate plate and shell specimens were formed by carbon-epoxy prepregs Fiber-Cote E765 / Toray T-700. Two stacking sequences, $(0/90)_{4s}$ and $(\pm 45)_{4s}$, were considered and denominated cross-ply and angle-ply. The CLD utilized to improve the impact strength is 3M damping foil SJ-2552. At last, two kinds of impact velocities and impactor masses were considered.

The nomenclatures of CLD specimens which subjected to different impact energy are shown in table 1 and table 2.

Table 1. Nomenclature - CLD laminate plates

Specimens	Impact vel.	Impactor mass	Nomenclature
$(\pm 45^0)_{4s}$	1.41 *m/s*	2.95 *kg*	Pa(d)-v1w1
		5.73 *kg*	pa(d)-v1w2
	3.05 *m/s*	2.95 *kg*	pa(d)-v2w1
		5.73 *kg*	pa(d)-v2w2
$(0^0/90^0)_{4s}$	1.42 *m/s*	2.95 *kg*	pc(d)-v1w1
		5.73 *kg*	pc(d)-v1w2
	3.05 *m/s*	2.95 *kg*	pc(d)-v2w1
		5.73 *kg*	pc(d)-v2w2

Table 2. Nomenclature - CLD laminate shells

Specimens	Impact vel.	Impactor mass	Nomenclature
$(\pm 45^0)_{4s}$	1.47 *m/s*	3.305 *kg*	sa(d)-v1w1
		6.05 *kg*	sa(d)-v1w2
	3.05 *m/s*	3.305 *kg*	sa(d)-v2w1
		6.05 *kg*	sa(d)-v2w2
$(0^0/90^0)_{4s}$	1.42 *m/s*	3.305 *kg*	sc(d)-v1w1
		6.05 *kg*	sc(d)-v1w2
	3.05 *m/s*	3.305 *kg*	sc(d)-v2w1
		6.05 *kg*	sc(d)-v2w2

Except low-velocity impact experiments, quasi-static simulation has also been utilized to simulate the impact responses.

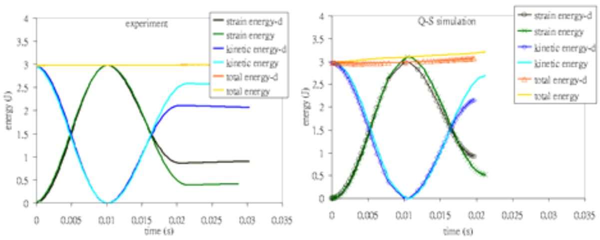
Luo and Lee[1-2] had verified the accuracy of quasi-static simulation. If the relationships of force-displacement can be obtained from static crush test, the responses of low-velocity impact can be simulated for the same boundary conditions.

Discussions

Comparing the results of laminate structures with/without CLD subjected to low-velocity impact, there are three kinds of phenomenon after impact.

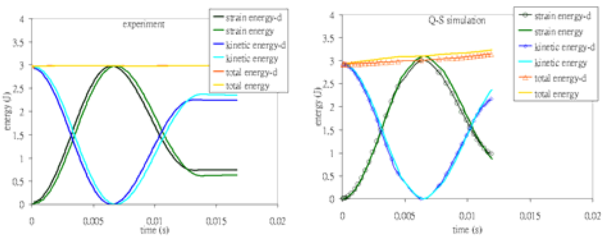
The first kind, rebound proceeding of impactor is in existence for laminate specimens with/without CLD after impact. The second kind, rebound proceeding of impactor is not in existence for laminate specimens with/without CLD after impact. The third kind, rebound proceeding of impactor is just in existence for CLD laminate specimens.

Fig. 1 and fig. 2 show a part of the first kind results. For the first kind results, the laminate specimens with CLD all have lower impactor kinetic energy. It means CLD absorbed more impact energy.



（a）Experiment （b）Q-S simu.

Fig.1 v=1.41m/s，m=2.95kg，pa(d)-v1w1



（a）Experiment （b）Q-S simu.
Fig.2 v=1.41m/s，m=2.95kg，pc(d)-v1w1

Table 3 shows all the cases that conformed to the first kind results and compares the CLD adhering efficiency. In table 3, we can observe clearly that CLD adhering efficiency of angle-ply plates is better than cross-ply plates, but adhering efficiency of shell specimens is on the contrary.

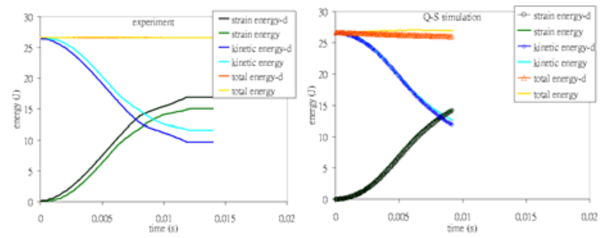
For 3M damping foil SJ-2552, it utilized shear deformation to absorb the dynamic loading energy. Besides, if CLD specimens have higher vibration frequency, the better energy-absorbed efficiency will be accompanied. Therefore, angle-ply plates have more obvious deformation and cross-ply shells have higher vibration frequency are both have better adhering efficiency.

Table 3. Estimates of CLD efficiency
(Exist impactor rebounded process)

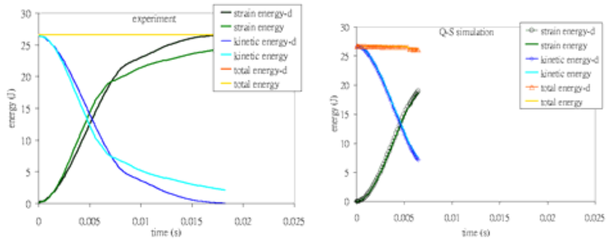
Specimens	Strain energy E_s no CLD (J)	Strain energy E_s CLD (J)	ΔE_s (J)	ΔE_k (J)	Exp. Δ/no CLD (%)	Q-S simu. Δ/no CLD (%)
Pa(d)-v1w1	0.3994	0.8807	0.4813	0.4801	**18.55**	**18.86**
Pa(d)-v1w2	1.1499	1.9194	0.4995	0.7688	**16.86**	**15.53**
Pc(d)-v1w1	0.6348	0.7478	0.113	0.129	**5.45**	**8.43**
Pc(d)-v1w2	1.1524	0.8793	0.2731	0.2847	**5.81**	**8.37**
Pc(d)-v2w1	4.7246	2.5523	2.1723	2.1863	**19.53**	**13.888**
Sa(d)-v1w1	2.1435	2.0127	0.1308	0.1394	**8.77**	**8.10**
Sa(d)-v1w2	3.7199	3.4975	0.2224	0.2682	**8.78**	**7.98**
Sc(d)-v1w1	1.3739	0.9992	0.3747	0.375	**14.512**	**10.79**
Sc(d)-v1w2	9.4738	4.2029	0.2709	0.2710	**13.082**	**10.429**

Fig. 3 and fig. 4 show a part of the second kind results. For the second kind results, the impactor penetrates the laminate specimens after impact and the specimens with CLD are all have the lower impactor kinetic energy. It means CLD can absorb more impact energy and reduce the penetrated velocity of impactor effectively.

Table 4 shows all the cases that conformed to the second kind results and compares the CLD adhering efficiency.



（a）Experiment （b）Q-S simu.
Fig.3 v=3.05m/s，m=5.73kg，pa(d)-v2w2



（a）Experiment （b）Q-S simu.
Fig.4 v=3.05m/s，m=5.73kg，pc(d)-v2w2

Table 4. Estimates of CLD efficiency
(Exist impactor penetrated process)

Specimens	$E_{sd} - E_s$ ΔE_s	Initial kinetic energy E_{k0}	$\triangle E_s / E_s$ %	$\triangle E_s / E_{k0}$ %
Pa(d)-h2w2	1.8635	26.6516	12.365	6.992
Pc(d)-h2w2	2.1408	26.6516	8.736	8.0325
Sa(d)-h2w2	3.094	28.14	18.005	10.775
Sc(d)-h2w1	10.98	15.372	8.740	7.137
Sc(d)-h2w2	1.524	28.14	10.599	5.41

For the third kind results, rebound proceedings of impactor are just in existence for CLD laminate specimens. The CLD specimens are stronger than common specimens qualitatively.

Conclusions

Laminate specimens adhering CLD can absorb low-velocity impact energy effectively has been confirmed in this study. Furthermore, the accuracy of quasi-static simulation has also been confirmed.

References

1. G. M. Luo, Y. J. Lee, Static crush experiments and simulations of laminated composite plates and shells with constrained layered damping. Journal of Composite Structures, 2008, 85, 64-69.
2. G. M. Luo, Y. J. Lee, Simulation of constrained layered damped plates subjected to low-velocity impact using a quasi-static method. Journal of Composite Structures, 2009, 88, 290-295.