Rubber-Filled 샌드위치 복합재료의 진동 특성 평가

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Dynamic Performance of Rubber-Filled Sandwich Composite

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Key Words : Sandwich composite, Honeycomb, Rubber, Natural frequency, Damping

Abstract

A new sandwich composite was investigated in this paper. The honeycomb core of this composite was filled with viscoelastic material in order to obtain an improved damping performance. The viscoelastic fillings in the honeycomb cells was hoped to act as dampers and provide the function of energy dissipation in this combined material system. Dynamic test was set up to the specimens with various stacked carbon/epoxy laminate facesheets, $[0/90]_{4s}$, $[0/45/-45/90]_{2s}$, $[45/-45]_{4s}$. Frequency response, displacement response and damping ratio were checked and compared for the both groups of specimens, with and without rubber fillings. The experimental results provided a good agreement with our material design concept.

1. Introduction

Sandwich composite has gained great reputation in the aircraft and aerospace industries because of its high strength to weight and stiffness to weight ratios. Typically sandwich composite is formed by bonding thin, strong facesheets to a thick, lightweight core. Each component of this composite is relatively weak and flexible but when working together they provide an extremely stiff, strong and lightweight structure. Sandwich composite is mainly applied for the structural purposes while it does have many other attributes, such as energy absorption, radio-frequency shielding, sound insulation [1] and etc. Recently with the development of vibration and noise control, the damping performance of sandwich composite has attracted many researchers' attention.

One construction of sandwich structure for damping purpose is that with viscoelastic core. The theoretical approach could be found in the works of Shyh-Chin Huang et al. [2-3]. The frequency response and damping effect of three layer sandwich thin shell and circular plate with viscoelastic core were studied in their papers. The general differential equations of motion were derived for this type of composite structure. A.W. van Vuure et al. [4] developed a sandwich-fabric panel with a viscoelastic layer for damping configuration. Jong Hee Yim et al. [5] investigated the damping behavior of a 0° laminated composite sandwich beam with a viscoelastic layer. Q.J. Zhang and M.G. Sainsbury [6] analyzed the vibration of rectangular damped sandwich plates by Galerkin element method. Researches about non-linear vibration of multilayer sandwich beam with viscoelastic layers were provided by H.-H. Lee [7]. Further, the vibration characteristics of partially covered sandwich structure with viscoelastic damping layers were also investigated by several researchers [8-10].

Another idea is performed on honeycomb sandwich composite. The core cells of the honeycomb structure provide readily free space for the dampers to be inserted into. The following papers made great efforts around this topic. B. Wang and M. Yang [11] carried out an experimental investigation on the damping behavior of laminated honeycomb cantilever beams with fine solder balls enclosed in the cells as dampers. The damping variation was found to be effective in reducing the amplitude without significantly shifting the natural frequency of the cantilever. U.K. Vaidya et al. [12] considers sandwich constructions with reinforced cores by way of three-dimensional Z-pins embedded into form, honeycomb cells filled with foam, and hollow/space accessible Z-pin. These designs offer added advantages

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over conventional constructions load bearing by enabling functions such as increase transverse stiffness, tailor vibration damping, impact damage and etc.

In this paper, a combined sandwich composite structure is presented. It is formed with a honeycomb core and viscoelastic fillings. The honeycomb core enhances the stiffness of entire composite structure. The viscoelastic fillings inserted in the honeycomb cells can provide good energy dissipation property and act as dampers in this combined material system. Primarily the damping effect of this material system is the first of our concerns. Experiments are performed under several conditions to identify the damping performance of this new material concept.

2. Structure description

Typical honeycomb core sandwich composite is constructed by facesheets, honeycomb core, and adhesive films, shown in Fig. 1(a). Fig. 1(b) is the section view of a common hexagon honeycomb core. The concept of our material model is illustrated in Fig. 1(c). The cells of the honeycomb core are filled with viscoelastic material, such as rubber. This concept optimizes the relationship between the honeycomb core and rubber and utilizes the benefits of both, that is, stiffness from honeycomb core and damping effect from rubber. Further, the cell walls of the honeycomb core are backed up by the rubber so that the total surface allows external forces to dissipate over a much larger area than that offered by the honeycomb core alone. This effect leads to a great resistance to shock-wave propagation along the surface, which means less vibration.

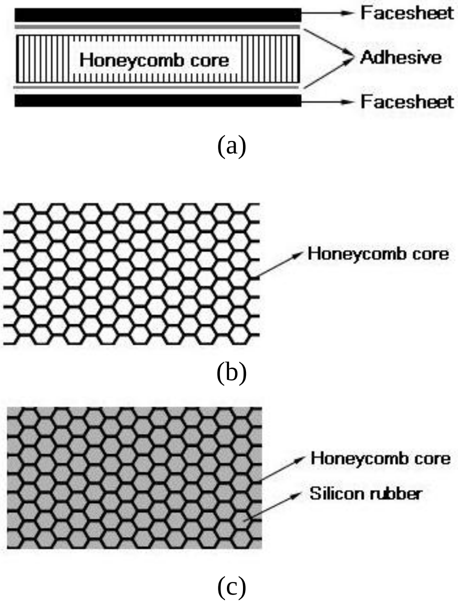


Fig. 1 Concept of rubber filled sandwich composite (a) sandwich structure (b)honeycomb core (c) rubber filled honeycomb core

A similar concept can be found in the paper of Woo-Young Jung and Amjad J. Aref [13]. They also proposed a combined honeycomb and solid viscoelastic material system for structure damping applications. In their study, the viscoelastic material was laid between the facesheets along with the honeycomb core. Functionally the viscoelastic material is independent to the honeycomb core in the whole structure only if the interface material is stiff enough to resist deformation at the interface. While in this study, the rubber is inserted into the honeycomb cells and works together with the cell walls. Thus, it is difficult to have the sliding at the interface in cell unit and expected to provide a stable and continuous damping system.

The shiniest merit of honeycomb structure is lightweight. Any filling will increase the weight of the whole body. Normally it is not recommended to fill the honeycomb cores just for strength purpose. Detailed description can be referred to Tom Britzer [14]. So the material described in this study should better be applied in the vibration-sensitive parts.

3. Experiments

3.1 Material components

The facesheets of the sandwich composites in this study were 16-ply carbon/epoxy laminates, which were stacked by USN125 prepreg and formed in autoclave. This kind of resin-containing carbon /epoxy prepreg was fabricated by SK Chemicals. The honeycomb core used in this study was Nomex-5/32-2.4 supplied by Hexcel Composites. The selected hexagon honeycomb core had a nominal cell size of 5/32 in and a core thickness of 10 mm with a nominal density as high as 2.4 pcf (pounds per cubic foot). The adhesive used to bond the facesheets to the honeycomb core was FM 73 film from Cytec Industries Inc. It was a 0.05 mm thick toughened epoxy layer reinforced with polyester fabric.

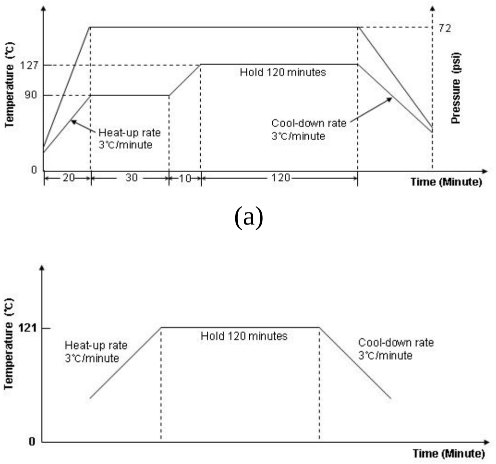
3.2 Preparation of specimen

For damping tests, two group of sandwich composite specimen were fabricated under laboratory conditions. One is the common honeycomb sandwich composite structure and the other is rubber filled one.

The face-skin laminate panels of thickness 1 mm with lay-up carbon/epoxy prepreg, USN125. Three types of facesheets were prepared with different stacking sequence: $[0/90]_{4s}$, $[0/45/-45/90]_{2s}$, $[45/-45]_{4s}$, which were fabricated using an autoclave under the curing cycle shown in Fig. 2(a). The laminates were cut to dimensions 150 mm × 100 mm by a diamond cutter. The honeycomb core was cut with the ribbon direction in the longitudinal direction of the facesheet panel.

For the first group the pre-cured facesheets subsequently bonded to the Nomex honeycomb core by the FM 73 adhesive film which could develop an adequate fillet bond to the selected core. After fixed by

G-clamp the specimens were cured in the chamber. Curing cycle was adopted as follows: 1 hour from the ambient temperature to 121°C; 2 hours at 121°C; and 1 hour from 121°C to the ambient temperature, as shown in Fig. 2(b).



(a)

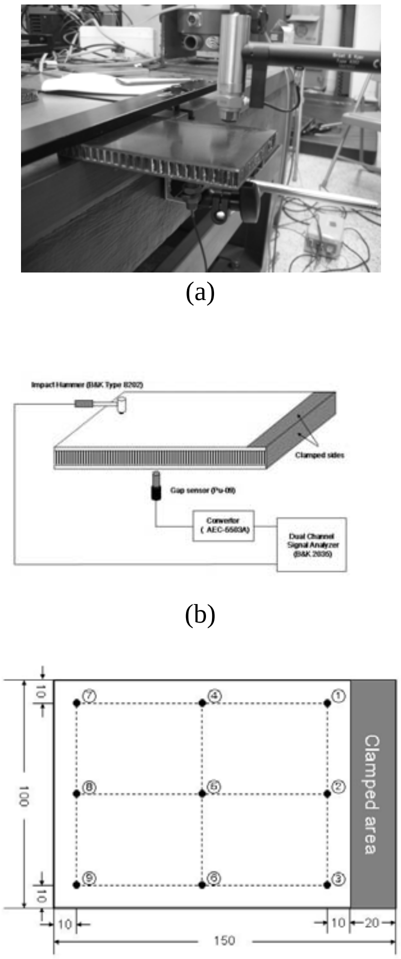
(b)

Fig. 2 (a) Curing cycle of facesheet (b) Curing cycle of sandwich composite panel

As to the second group, one piece of facesheets was first bonded to honeycomb core. Cavities were naturally formed between the facesheet and honeycomb-core cell walls and liquid silicon rubber (LSR) was injected into the cavities. The LSR chosen in this study was ShinEtsu Silicon one component RTV. This kind of silicon rubber is originally sealed in liquid state. After curing it became solid silicon rubber. Obviously liquid rubber is the only choice to achieve our proposed material model. After injection the other piece of facesheet with adhesive film was covered to the honeycomb core. The specimens were also cured in the chamber after fixed by G-clamp. Curing cycle could be referred to that of the first group. At the end the cycle specimens were carefully brought out of the oven and then placed in room environment for three days to ensure silicon rubber fully vulcanized.

3.3 Experimental settings

The vibration tests were conducted on prepared specimens on a horizontal table. The specimens were fixed in cantilever state as shown in Fig. 3(a). The width of clamped area is 20mm. The gap sensor in Fig. 3(b) was set under the sandwich composite panel with 4mm gap. As known, the gap sensor is a non-contacting minute displacement measuring system and is very suitable for the accurate measurement of static and dynamic displacement. B&K Type 8202 impact hammer was used to hit the cantilevered sandwich panels. The hammer in this study was the type with plastic tip. The force range of was 300 to 1000 N and approximate frequency range was 0 to 2000 Hz.



(a)

(b)

(c)

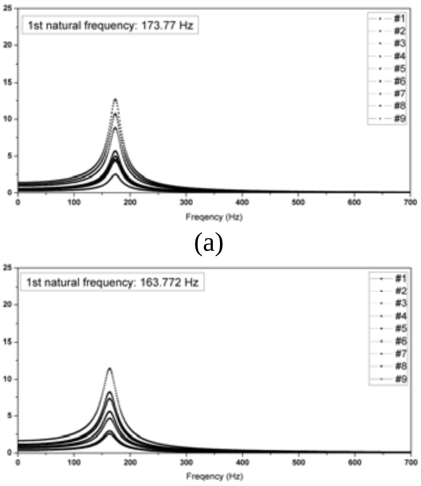
Fig. 3 (a) Dynamic test settings (b) Schematic graph of instrument settings (c) Dimensions of test points

The impact hammer and gap sensor was linked to the two channels of B&K Signal Analyzer Unit Type 2035, which monitored the real time signal during the test. Impact hammer hit at 9 points labeled in Fig. 3(c). For each success strike we checked the coherence, frequency and displacement, and then saved them in ASCII code. The test data were processed on PC using ME'Scope Visual Modal Pro, the commercial soft package provided by Vibrant Technology Inc. The frequency response data were curve fitted. Time response data in ASCII form were read by graph plotting software.

4. Results and discussion

First of all the frequency responses of each specimen were studied. For the convenient, the specimens with the same stacking facesheets were listed together for comparison. Only the first mode was concerned here so that frequency range was confined from 0 to 700 Hz.

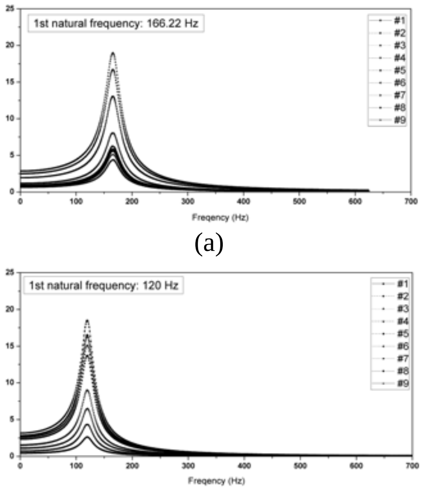
Fig. 4 gave the frequency response curves of the specimen with $[0/90]_{4s}$ facesheets. Fig. 4(a) was the type of common sandwich panel and Fig. 4(b) was that with rubber filled. Such description could be repeated to Fig. 5 with $[0/45/\text{-}45/90]_{2s}$ facesheets and Fig. 6 with $[45/\text{-}45]_{4s}$ facesheets. As shown in Fig. 4 ~ 6, the responses of the 9 positions illustrated in Fig. 3(c) had peak points happened at nearly the same frequencies. This frequency was recognized as the 1st natural frequency of the sandwich composite panel, whose values were listed in each figure. As seen in the 3 groups of results, the natural frequency dropped with the rubber filled in the honeycomb core. This shift of frequency was due to the change of structure density when the mass of rubber was added to the sandwich panel.



(a)

(b)

Fig. 4 Frequency response of sandwich composite panels with $[0/90]_{4s}$ facesheets
(a) No rubber filled (b) Rubber filled



(a)

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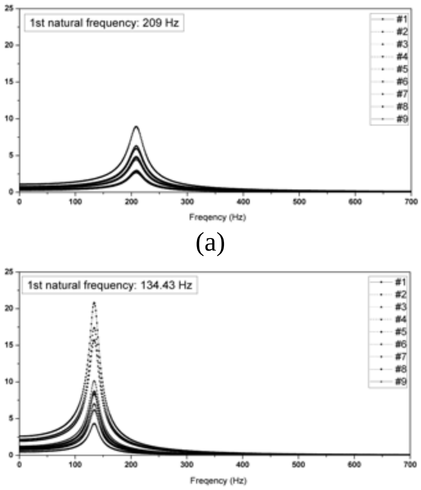
Fig. 5 Frequency response of sandwich composite panels with $[0/45/\text{-}45/90]_{2s}$ facesheets
(a) No rubber filled (b) Rubber filled



(a)

(b)

Fig. 6 Frequency response of sandwich composite panels with $[45/\text{-}45]_{4s}$ facesheets
(a) No rubber filled (b) Rubber filled

As damping properties of the rubber filled sandwich panel is the first of our concern, the time histories of each specimen were brought out for analysis. Normally in a free vibration of an under-damped system displacement amplitude decays exponentially with time, as shown schematically in Fig. 7. The rate of decrease depends on the damping ratio, which can be used to evaluate the material capability of energy dissipation. Here we use ζ to denote the damping ratio. By applying the theory of logarithmic decrement [15], we can find that displacement of the panel can be expressed in Eq. (1) at time t.

$$A_t = A_0 e^{-\zeta\omega t}\cos(\omega t+\varphi) \qquad (1)$$

Where A_t is amplitude of the decay curve at time t. A_0 is the initial amplitude. φ is the phase angle. For full-cycle turning points, we can compute the logarithmic decrement through

$$\zeta = \frac{1}{\omega t}\ln(A_0 / A_t) \qquad (2)$$

However, the estimate of damping ratio based on Eq. (2) was difficult due to the presence of either or both of two problems such as mean position offset, unsymmetrical decay, ambiguous initial points and etc. So several points should be selected and the result of damping ratio was obtained by averaging over these points.

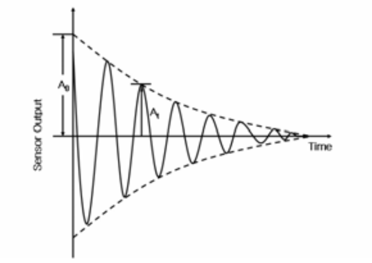
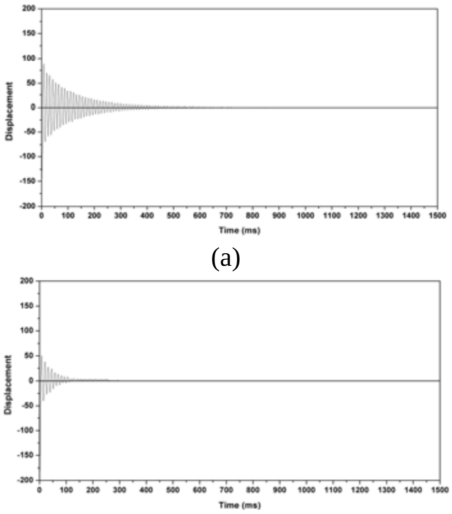


Fig. 7 Schematic graph for damping ratio calculation

Fig. 8~10 provided the time response decay curve measure by gap sensor for the specimens with $[0/90]_{4s}$, $[0/45/-45/90]_{2s}$, $[45/-45]_{4s}$ facesheets respectively. From the graphs one could find that the specimen with rubber filled had much short response time. The excited displacement was damped to zero very quickly with the help of rubber. The response time of common sandwich panels is about 600ms, while that of rubber filled sandwich panel only need 300ms.



(a)

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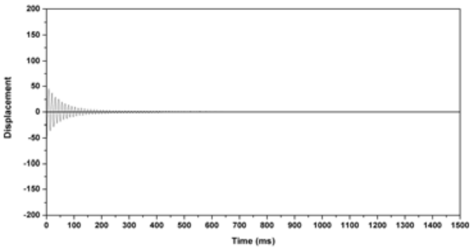
Fig. 8 Displacement response of sandwich composite panels with $[0/90]_{4s}$ facesheets
(a) No rubber filled (b) Rubber filled



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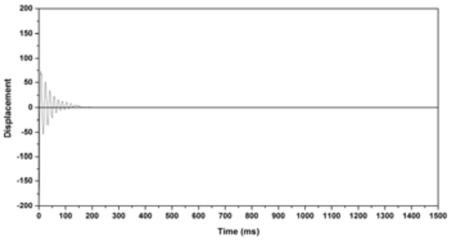
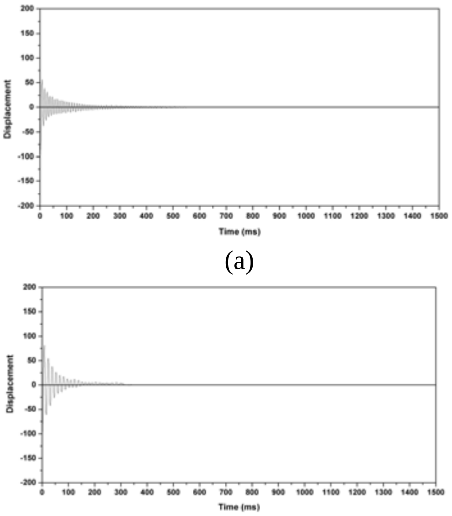


(b)

Fig. 9 Displacement response of sandwich composite panels with $[0/45/-45/90]_{2s}$ facesheets
(a) No rubber filled (b) Rubber filled



(a)

(b)

Fig. 10 Displacement response of sandwich composite panels with $[45/-45]_{4s}$ facesheets
(a) No rubber filled (b) Rubber filled

Fig.11 gave the comparison graph of the damping ratios calculated by Eq. (2). One can also find that the rubber play a great role of energy dissipation and structure damping from this visualized graph.

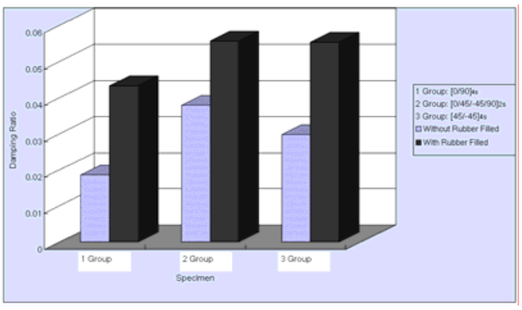


Fig. 11 Chart of damping ratios

5. Conclusion

The experimental study of viscoelastic material filled sandwich composite was presented for the concern of dynamic performance. From the test result the following conclusions could be drawn:

i) The sandwich panel with rubber filled had much short response time. The decay time of common sandwich panels is about 600ms, while that of rubber filled sandwich panel only need about 300ms.

ii) The damping ratios of the sandwich panels with rubber filled were 2.35, 1.46, 1.86 times larger than that of common sandwich panels.

iii) The natural frequency dropped with the rubber filled in the honeycomb core. This shift of frequency was due to the change of structure density when the mass of rubber was added to the sandwich panel.

iv) The sandwich composite panel with rubber filled showed a great capacity of energy dissipation and structure damping effect.

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