Transactions on Engineering Sciences vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3533

Eigenfrequency analysis method for single-lap adhesive joints of CFRP laminates

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Abstract

The purpose of this study is to propose a new numerical modeling of single-lap joints of CFRP laminated composites. The eigenvibration mode is always three-dimensional behavior deformation which includes in-plane and out-plane deformations. This indicates that the finite element analysis requires three-dimensional solid element. In case that the adherend plane structure is modeled by the conventional solid element, the huge elements and huge solution time are unavoidable. Therefore, we proposed the new numerical model in this study. This model is construction of orthtropic-shell element and beam element, which represent adherend and adhesive, respectively. Shell elements are connected with beam elements in the thickness direction to express adhesive layer. The space between shell and beam elements is combined by rigid link to the correspond the beam elements length to the real adhesive thickness. Using this model, the eigenvibration analysis of canti-levered CFRP single-lap joints structure were performanced. Influences of adhesive and adherend properties and adherend thickness upon eigenfrequency are also discussed. Hoop positions of the 1st and 2nd eigenvibration modes of CFRP adhesive joints are an free edge of specimen and the adhesive, respectively. In particular, it is confirmed that the 2nd eigenfrequency depends on shear deformability in adhesive layer.

1 Introduction

Recently the more complex composite structures have been required in various industries. Since the complex whole structure cannot be made of solely composite materials or one-piece, joining of composite materials to another is sometimes required. Especially a single lap joints structure is one of the most popular adhesive joint structures. In the single lap joints structure an adhesive interface has a special significance because of the lower rigidity in both the static and dynamic properties of the whole lap structure. This work describes the vibration damping properties of single-lap adhesive joints from both the analytical and experimental viewpoints. The numerical modeling for whole single-lap joints are performed by combining the elements constructed independently for adherends and adhesive layers. The eigenvibration mode is always three-dimensional deformation. This indicates that the simulation requires three-dimensional solid element in the finite element analysis. However, in case that the adherend plane structure is modeled by the conventional solid element, the huge elements and huge solution time are unavoidable. This is mainly caused by the large aspect ratio of the plane structure. Especially, the adhesive layer thickness is much smaller than other dimensions. It is necessary to shorten solution times and consider adhesive layer.[1] Therefore, we propose new numerical model which combined adherend and adhesive layers, respectively. The validity of the model and a few discussions are presented.

2 Analytical and experimental methods

Fig.1 shows the proposed numerical model in this study. This model is constructed independently modeled as adherend with orthtropic-shell element and adhesive with beam element respectively. Then shell elements are connected with beam elements in the thickness direction to express adhesive layer. The space between shell and beam elements is combined by rigid link to the correspond the beam elements length to the real adhesive thickness. Using the model, eigenfrequencies of single-lap joints of CFRP laminates were analyzed.

Fig.2 shows a shematic diagram of single-lap joints investigated. The single-lap joints consists of two adherends of composite laminate which are bonded together with adhesive layer. The overall length is 150mm, the width is 16mm, the lap length is 50mm, thickness of adherends are 1.0mm and thickness of adhesive layer is 0.1mm, as shown in Fig.2.

The boundary condition is clamped in one end and perfectly free for all the other ends. Fig.3 shows the mesh division in the proposed model. The number of shell elements, beam elements and nodes are 128, 50 and 265, respectively.

Table 1 shows the stacking sequences of composite adherends. The validity of the model proposed is checked through comparisons with experimental results. For this purpose, cantilever beam tests were carried out on 150mm and 16mm wide beam by using B&K T2034 dynamic signal analyzer, as shown in Fig.4, to measure the eigenfrequency and vibration mode. The vibration excitation force was applied by means of a magnetic transducer driving a thin steel disk bonded to the beam tip. The beam response was measured using a capacitive transducer.

3 Results and discussion

Table 2 compares the measured and predicted eigenfrequencies in the first two vibration modes. The good agreements indicate that the numerical simulation for the eigenfrequencies of single-lap joints can be successfully performed by the model proposed in this work.

The influence of fiber orientation angle on the vibration properties are now discussed. In case of the 1st flexural mode with fixed end, the eigenfrequency of adherend I material with orientation angle of 0 deg.(Type a and Type c) exists in the higher frequency side, as compared with 90 deg. orientation angle(Type b and d). This result will be explained from the fact that eigenfrequency depends upon the flexural rigidity of adherend I clamped, because the maximum stress occurs at the clamped area. On the other hand, the difference of eigenfrequency is not significant between adherends of Type c and Type d whose orientation angle is different. This fact indicates that the sensitivity to flexural rigidity of adherend at the clamped area is comparatively small in the 2nd mode than in the 1st mode.

The influence of thickness of adherend on the eigenfrequency is investigated by using the proposed model. In the first case, the thickness of adherend I was fixed to 2.5mm and the thickness of adherend II was changed to 1.0, 2.5, 5.0, 7.5 and 10mm. In the second case, the thickness of adherend II is 2.5mm and the five different thickness, 1.0, 2.5, 5.0, 7.5 and 10mm, were employed for adherend I. In both cases, the thickness of adhesive layer represented by the beam element length, was assumed to be 0.1mm.

As shown in Fig. 5 (a), the eigenfrequency in the 1st vibration mode in the first case keeps constant with an increase of thickness of adherend II. As already mentioned the previous section, the eigenfrequency depends upon the flexural rigidity of adherend I. It is considered that the eigenfrequency in the 1st vibration mode in this analysis kept constant, because of a constant thickness which means constant rigidity of the adherend I. On the other hand, eigenfrequency in the 2nd mode showed the maximum value, when the thickness of adherend I equals to that of adherend II. When the thickness of adherend I equals to that of adherend II, the flexural rigidity is equal for both the adherends, the hoop position exists in the adherend area of joint where the thickness becomes maximum. In other words, this may be a reason why the eigenfrequency has a peak in this case. The eigenfrequency in the 1st vibration mode for the first case depends upon the flexural rigidity at the clamped area, while 2nd vibration mode depends upon the flexural rigidity in the hoop position. In the second case of study for influence of thickness, eigenfrequency in the 1st mode increases with an increase of thickness of adherend I, as shown in Fig. 5 (b). Also in the 2nd mode, eigenfrequency becomes higher as the thickness of adherend is increased and this tendency is completely different for the result in the first case. The influence of orientation angle on the vibration properties are now discussed. The stacking sequences of composite adherends I and II are 0_8 and 0_8, 15_8 and 15_8, 30_8 and 30_8, 45_8 and 45_8, 60_8 and 60_8, 75_8 and 75_8, 90_8 and 90_8. Table 4 shows comparison between analytical and experimental results in the 1st and 2nd eigenfrequencies in order to check the validity of the proposed model. The good agreements indicate that the eigenvibration analysis of single-lap joints can be successfully performed by the model proposed in this work. In case of both the 1st and 2nd flexural modes, the eigenfrequency of adherend material with orientation angle of 0 deg. exits in the higher frequency side, as compared with 90 deg. orientation angle. In a word, eigenfrequencies in 1st and 2nd modes becomes lower as orientation angle of adherend increases. This result will be explained from the fact that eigenfrequency depends upon the flexural rigidity of adherends.

Moreover 15 deg. orientation angle is found that twist coupling effect is larger than other orientation angle.

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4 Conclusions

A new numerical modeling for a single-lap adhesive joint of CFRP laminates was investigated in this work. The proposed model consists of shell and beam elements, that correspond to adherend and adhesive, respectively. Using the numerical model performed eigenfrequency analyses and both analytical and experimental results were compared. Therefore the following results were obtained.

1)It was concluded that the proposed model which is constructed with shell and beam elements that correspond to adherend and adhesive, respectively is effective for the eigenvalue problems.

2)It was confirmed that the 1st and 2nd eigenvibration modes were sensitive to the adherend rigidity clamped and hoop's flexural stiffness, respectively.

Reference

[1] Tanimoto, Y., Tange, A., MAEKAWA, Z. & Nishiwaki, T., Eigenfrequency analysis method of adhesive joints of CFRP laminates, Proceedings of the fifth Japan International SAMPE Symposium, pp. 1707-1710, 1997

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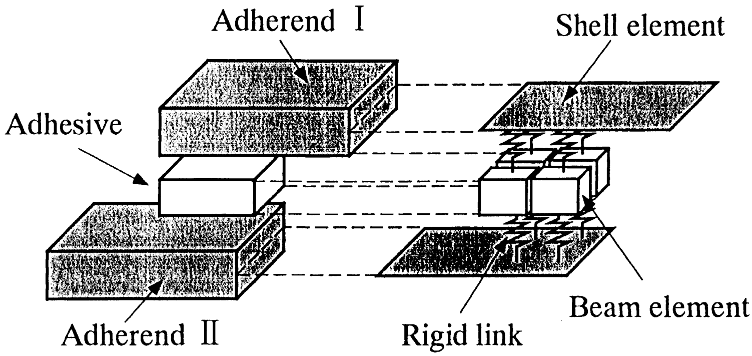

Figure 1: Basic concept for modeling

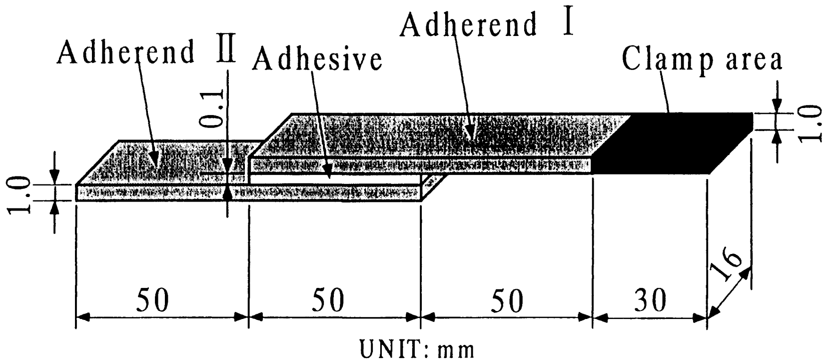

Figure 2: Schematic diagram of single-lap joints

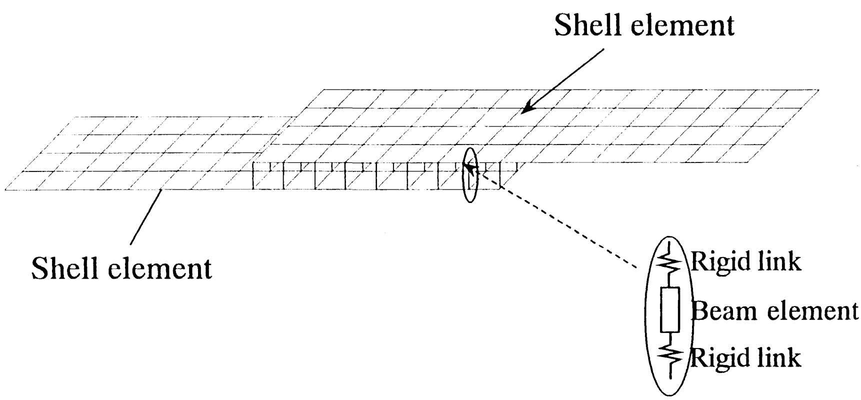

Figure 3: Finite element division by model

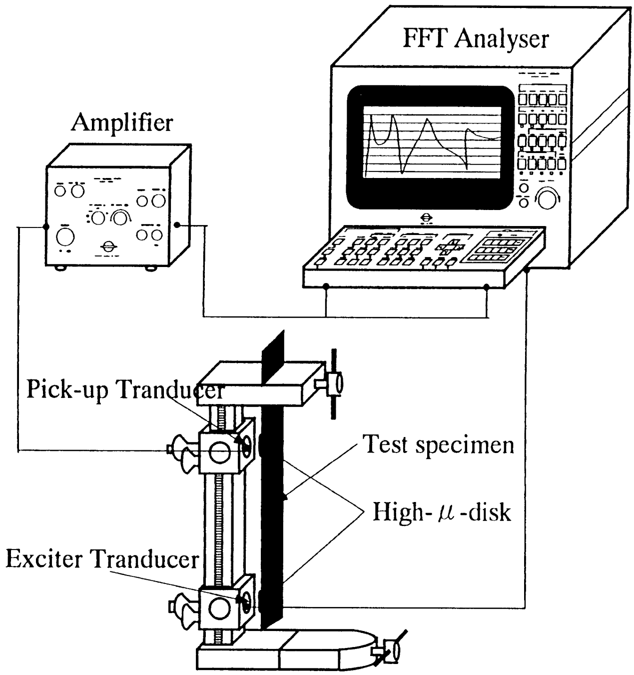

Figure 4: Apparatus in complex modulus

Table 1: Patterns of analysis

Type	Adherend Ⅰ	Adherend Ⅱ
a	0	0
b	90	90
c	0	90
d	90	0

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Table 2: Comparison between analytical and experimental results for 1st and 2nd eigenfrequencies(Type of a~d)

Type	1st flexural frequency (Hz)			2nd flexural frequency (Hz)		
	Experiment (Hz)	Analysis (Hz)	Error(%)	Experiment (Hz)	Analysis (Hz)	Error(%)
a	51.00	55.69	9.20	347.2	375.4	8.12
b	14.67	17.50	19.29	112.0	129.7	15.80
c	47.14	53.20	12.86	178.0	198.1	11.29
d	16.20	17.80	9.88	159.5	175.2	9.84

Error=(Analytical results-Experimental results)/Experimental results

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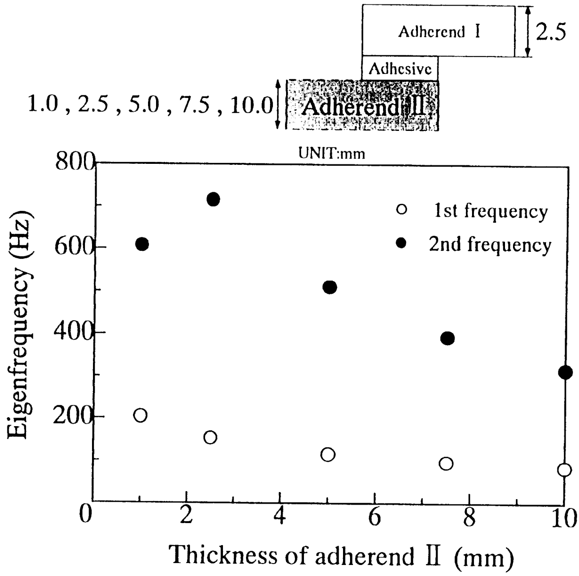
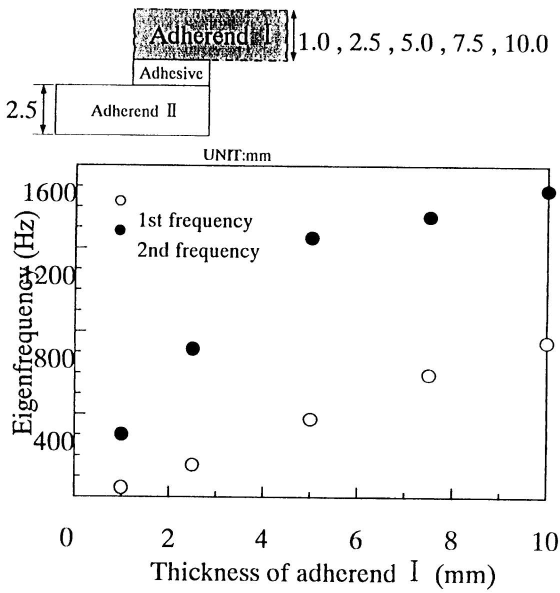


(a) Influence of adherend II thickness



(b) Influence of adherend I thickness

Figure 5: Influence of adherend thickness to eigenvibration

Table 3: Comparison between analytical and experimental results for 1st and 2nd eigenfrequencies(0 deg.~90 deg.)

Fiber orietation angle (θ)	1st eigenfrequency			2nd eigenfrequency		
	Analysis (Hz)	Experiment(Hz)	Error (%)	Analysis (Hz)	Experiment(Hz)	Error (%)
0	55.69	51.00	9.20	375.4	347.2	8.12
15	41.12	38.42	7.03	310.2	273.8	13.29
30	27.52	26.14	5.28	214.2	208.7	2.64
45	21.13	18.94	11.56	158.5	150.4	5.39
60	18.47	16.72	10.47	136.7	131.4	4.03
75	17.61	15.10	16.62	130.5	118.9	9.76
90	17.50	14.67	19.29	129.7	112	15.80

Error=(Analysis-Experiment)/Experiment