BENDING STRENGTH ANALYSIS OF CENTRALLY-DEBONDED COMPOSITE SANDWICH BEAM USING TAGUCHI METHOD

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ABSTRACT

Sandwich structure, bonded with high strength facesheets and light-weighted core material, is commonly used; however the debonding between facesheet and core occurs occasionally during the manufacturing process. This facesheet/core debonding affects the strength of sandwich structure.

In this study, the bending strength of centrally-debonded composite sandwich beam was investigated using Taguchi's method. Composite sandwich beams, made of graphite/epoxy laminate as facesheet and MWNTs/epoxy nanocomposites as core material, with a central facesheet/core debond and under four point bending, was analyzed by experiment and using finite element method. The Taguchi's method was used to obtain the optimal bending strength based on three parameters, i.e., the centrally-debonding length, the fiber orientation of the facesheet laminate and MWNTs content in core. The results showed that the optimal bending strength occurred for 50 mm (shortest) debonding length, $[0^o/45^o]$s fiber orientation of the facesheet laminate and 2 wt% (highest) MWNTs content in core for the cases considered.

Keywords: Bending strength, Sandwich beam, Composite beam, debonding, Taguchi metnod.

1. INTRODUCTION

With high specific strength, high specific stiffness and the ability of variable fiber orientation to have required mechanical property, composite materials becomes an competitive substitute for use in various structures. Sandwich structure, bonded with high strength facesheets and light-weighted core material, is commonly used; however the debonding between facesheet and core occurs occasionally during the manufacturing process. This facesheet/core debonding affects the strength of sandwich structure. Mouritz and Thomson (1999) studied the compression, flexure and shear properties of a sandwich composite containing defect by four-point bending test. Hohe and Becker (2001) invesatigated the delamination of facesheet/core bond in sandwich panels. Gdoutos *et al.* (2001) assessed both the linear and nonlinear behavior of composite sandwich beams under three-point bending. Fiedler *et al.* (2006) found that the fracture toughness of matrix epoxy could be improved for nano-reinforced composites using single-walled and multi-walled carbon nanotubes.

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Vadakke and Carlsson (2004) investigated experimentally the compression failure of sandwich specimens with facesheet/core debond and found that the compressive strength was higher for the same crack length for the denser core material. Yeh *et al.* (2006) investigated the mechanical properties of MWNT/phenolic composites and demonstrated that adding MWNT would improve Young's modulus and tensile strength of composites. Yeh and Chiu (2010, 2011) studied the bending behavior of sandwich beam under pure bending with a central debonding region experimentally and using finite element method.

In this study, composite sandwich beams under four point bending, made of graphite/epoxy laminate facesheet and MWNTs/epoxy nanocomposites core and with a central facesheet/core debond, were studied. The Taguchi method (Li 1993) was used to obtain the optimal bending strength based on three parameters considered, i.e., the centrally-debonding length, the fiber orientation of the facesheet laminate and MWNTs content in core.

2. EXPERIMENTAL

In this study, sandwich beam specimens were fabricated according to ASTM C393-00 (2000). The graphite/epoxy laminate facesheets are bonded with MWNTs/epoxy nanocomposites core material. A piece of teflon was placed between the upper facesheet and the core to form a central debonding region in the sandwich beam. The material properties of facesheet laminate and core were obtained from tensile tests. A four-point bending device, as shown in Figure 1, was placed on the testing machine to apply bending load on the sandwich beams. The load cell was used to measure the load and the load-displacement response of the sandwich specimen was obtained from experiment.

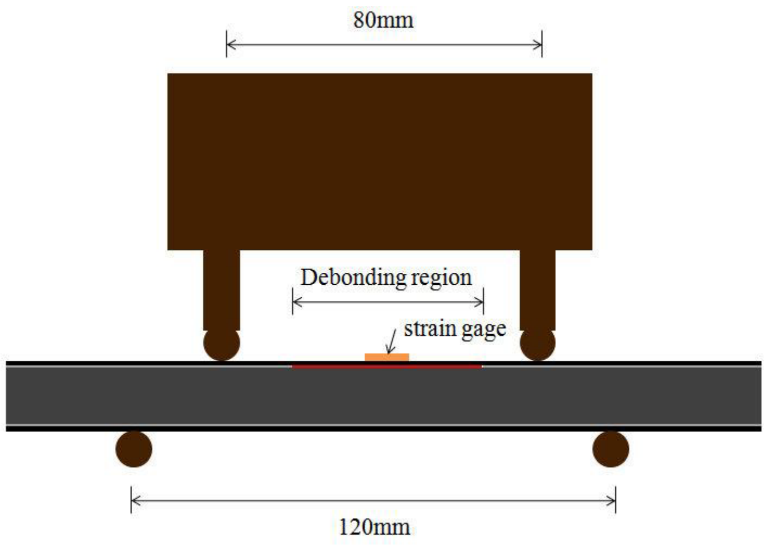


Figure 1: Centrally-debonded sandwich beam under four-point bending

3. FINITE ELEMENT ANALYSIS

The finite element software ANSYS (2006) was used to analyze the load-displacement response of sandwich beam with a central facesheet/core debonding region under four point bending. For facesheet laminate and core material, Plane 42 elements were used. The element Plane 42 has four nodes, each node having two degrees of freedom. The material properties of facesheet laminate and core material were obtained from experiment (Yeh and Chiu 2010) and used in the analysis. Since a piece of teflon was placed in the facesheet/core interface to make a centrally debonding region, the adhesive boundary at the debonding corner was modeled as a 45^{o} V-notch and five-layer model, including core material, upper and lower facesheets, two bonding layers made of epoxy, was constructed in finite element analysis (Yeh and Chiu 2011). The thickness of bonding layer was measured as 0.07 mm. Figure 2 shows the load-displacement response of a centrally-debonded sandwich beam. The strengths of the sandwich beams were found from experiment when the first further debonding (point B in Figure 2) of the adhesive layer occurred. The maximum normal stress theory based on the ultimate stress of the epoxy adhesive at the tip of the debonding region was applied to find the bending strength in the analysis.

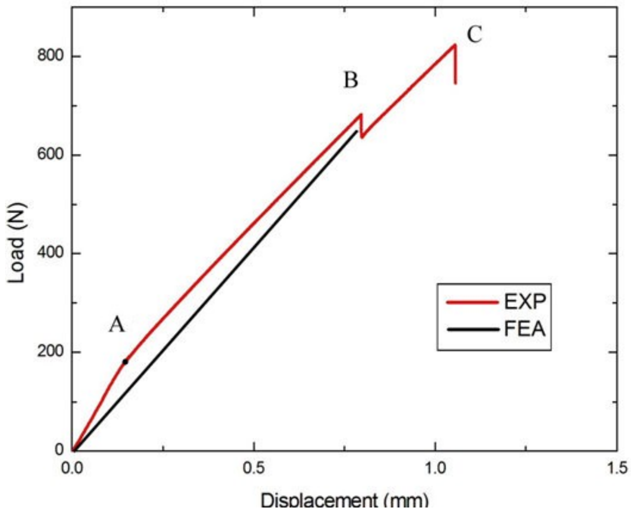


Figure 2: Load-displacement response of centrally-debonded sandwich beam

4. TAGUCHI METHOD

Taguchi method is used widely for robust engineering design. This method could obtain an optimal level combination by choosing proper Taguchi orthogonal array with control parameters and levels. Moreover, the effect of each control parameter could be obtained. Three control parameters, the fiber orientation of the facesheet laminate, MWNTs content in core and the centrally-debonding length, with three levels are selected as shown in Table 1. The Taguchi orthogonal array L_9 was adopted as shown in Table 2, in which 9 experiments, each repeated three times, were performed.

Table 1: Control parameters and levels

parameter	A θ in laminate $[0°/θ°]_s$	B MWNT wt% in core	C debonding length (mm)
Level I	0	0	50
Level II	45	1.0	55
Level III	90	2.0	60

Table 2: L_9 Orthogonal array

parameter	A θ in laminate $[0°/θ°]_s$	B MWNT wt% in core	C debonding length (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.1. Effect of control parameter

The quality of experiments was analyzed by the signal to noise ratio (S/N ratio) after experiments. The larger S/N ratio indicated the better quality and smaller variance (Li 1993). The mean value of the S/N ratio for the 9 experiments is 52.721 db with a maximum 54.665 db for the sixth experiment and a minimum 50.952 db for the seventh experiment.

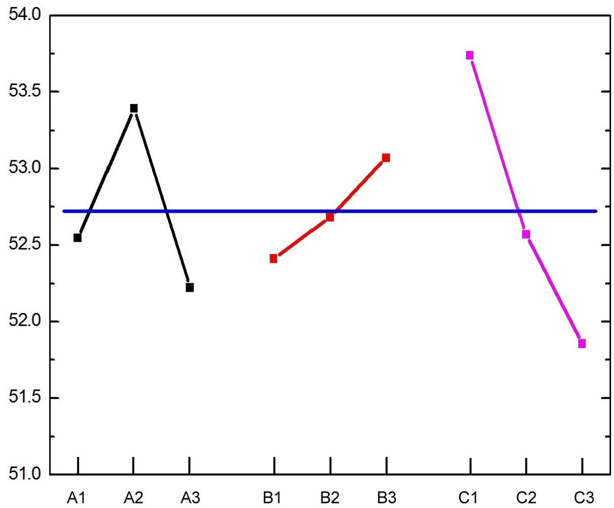
The average of S/N ratios at the same level for each control parameter resulted in the effect of each control parameter. For the fiber orientation of the facesheet laminate, three levels $[0°]_4$,$[0°/45°]_s$, $[0°/90°]_s$ were adopted. The S/N ratio was 52.545 db, 53.394 db and 52.224 db, respectively, with a maximum value for the level 2, $[0°/45°]_s$, since this case has better shear ability in addition to resist the normal force. For MWNTs content in core, three levels 0wt%, 1 wt%, 2 wt% were adopted. The S/N ratio was 52.410 db, 52.682 db and 53.070 db, respectively, with a maximum value for the level 3, 2 wt%, since this case has higher contents of MWNT in the core and thus higher Young's modulus of core. For the centrally-debonding length, three levels 50 mm, 55 mm and 60 mm were adopted. The S/N ratio was 53.738 db, 52.568 db and 51.856 db, respectively, with a maximum value for the level 1, 50 mm, since this case has least debonding length.

In summary, the effects of each control parameter are listed in Table 3. Figure 3 shows the S/N ratio versus control parameters, in which the horizontal line represents the average of all S/N ratios 52.721 db. The effect values are the difference between the maximum and the minimum values of

S/N ratios for each control parameter. The control parameter has larger effect with bigger effect value. For the three parameters considered, the centrally-debonding length has larger effect than the fiber orientation of the facesheet laminate than the MWNTs content in core. The results show that in our problem the optimal level combinations for bending strength of composite sandwich beams are fiber orientation of the facesheet laminate $[0°/45°]_s$, MWNTs content in core 2 wt%, and centrally-debonding length 50 mm.

Table 3: Effect of control parameters (db)

parameter	A θ in laminate $[0°/θ°]_s$	B MWNT wt% in core	C debonding length (mm)
Level I	52.545	52.410	53.738
Level II	53.394	52.682	52.568
Level III	52.223	53.070	51.856
Effect	1.171	0.660	1.882
Rank	2	3	1



Fiure 3: S/N ratio versus control parameters

5. CONCLUSIONS

In this paper, the bending strength of centrally-debonded composite sandwich beam was investigated by experiment and using finite element method. The composite sandwich beams, having graphite/epoxy laminate facesheet, MWNTs/epoxy nanocomposites core and a central facesheet/core debond were under four point bending. Three parameters, the centrally-debonding length, the fiber orientation of the facesheet laminate and MWNTs content in core, were adopted in the Taguchi method and the effects of each parameter were obtained. After analysis using Taguchi method, the centrally-debonding length had largest effect on the bending strength of the debonded composite sandwich beam; while the MWNTs content in core had the least effect. An optimal level combination for bending strength of composite sandwich beams was obtained, that is, the fiber orientation of the facesheet laminate $[0°/45°]_s$, MWNTs content in core 2 wt%, and centrally-debonding length 50 mm for the problem considered.

6. ACKNOWLEDGMENTS

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REFERENCES

ANSYS Release 10.0, ANSYS, Inc., PA, 2006.

ASTM C393-00 (2000). Standard Test Method for Flexural Properties of Sandwich Constructions. Annual Book of ASTM Standards.

Fiedler B, Gojny FH, Wichmann MHC, Nolte MCM, and Schulte K (2006). Fundamental aspects of nano-reinforced composites. Composites Science and Technology. 66, pp. 3115-3125.

Gdoutos EE, Daniel IM, Wang KA, and Abot JL (2001). Nonlinear behavior of composite sandwich beams in three-point bending. Experimental Mechanics. 41, pp. 182-189.

Hohe J and Becker W (2001). Assessment of the delamination hazard of the core face sheet bond in structural sandwich panels. International Journal of Fracture. 109, pp. 413-432.

Li CC (translator) (1993). Quality Engineer of Robust design, Taipei Books Co., Taipei, Taiwan. (in Chinese)

Mouritz AL and R. S. Thomson RS (1999). Compression, flexure and shear properties of a sandwich composite containing defects. Composite Structures. 44, pp. 263-278.

Vadakke V and Carlsson LA (2004). Experimental investigation of compression failure of sandwich specimens with facecore debond. Composites: Part B. 35, pp. 583-590.

Yeh MK, Tai NH, and Liu JH (2006). Mechanical behavior of phenolic-based composites reinforced with multi-walled carbon nanotubes. Carbon. 44(1), pp. 1-9.

Yeh MK and Chiu YW (2010). Bending behavior of sandwich beam with a central debonding region. Proceedings of the 7th Asian-Australasian Conference on Composite Materials (ACCM-7), November 15-18, Taipei, Taiwan, Paper No. THU-SE32-07

Yeh MK and Chiu YW (2011). Finite element analysis of centrally-debonded composite sandwich beam under four point bending. Advanced Materials Research. 335-336, pp 351-354.