하중에 대한 샌드위치보의 디자인 변수 선택

김종만,* 황효균,** 이진우, 김외열***

Selection of design variables in the Sandwich Beam for load resistance

Jongman Kim, Hyo-Kune Hwang and Jin-Woo Lee, Wae-Yeule Kim

Key Words : Sandwich Beam, Sandwich Structures …

ABSTRACT

It has been well-known that sandwich structures are efficient to resist bending loads by increasing the moment of inertia of the panel. However, the accurate theoretical prediction of failure load and its optimization of sandwich beams for strength under concentrated loads were so complicated. Moreover, the appropriate selection of the variables, such as face thickness, core density and core thickness of the sandwich beam with many theories has continuously researched to satisfy for the given strength to weight structural requirement. There will be interesting to investigate the effect of those variables with its optimization for the load resistance.

1. Introduction

Structural vessels, such as navel ships and private boats have used the sandwich structures to take an advantage of resisting the higher bending loads with the small addition of weight.[1] New skin materials in the composites and metals have been introduced into the marine industry with an advance of stronger adhesives. Either honeycomb or continuous materials with open geometric shape such as expanded polymer or syntactic foam have been widely used as a core material.

Many endeavors have been done with the optimized design for the stiffness of sandwich beams.[2] Additionally, it has also been an important issue to improve the strength of the sandwich beam for the concentrated loading. However, the analysis is so complicated that it could not have been predicted by the simpler theories. A significant improvement of higher order theory of Frostig at el.[3-5] has been introduced, based on treating each face to be an independent beam. A 3-D elasticity solution for layered orthotropic plate was originally developed by Pagano, Srinivas and Rao.[6] This solution has been employed for this analysis to model concentrated loading in sandwich beam.[7]

Broad ranges of core densities can be available for the foam material used in the core layer in the sandwich beam, and the progress of the recent researches on the mechanical properties of foams gives a big help for the theoretical analyses of sandwich structures.[8] The static force application, which was done with the beam bending in the laboratory tests, can be used for the results applicable for the impact loading, which is treated as quasi-static impact.

In this paper, an analytical method using the 2-D elasticity solution is employed to predict the failure loads of sandwich beam for the given concentrated loading and compared with the experimental lab test results in the point of the core density and different face thickness ratio. It will give useful information in the design of the off-optimized and optimized beams for the strength

* LG Electronics Inc.저자(kjm1968@lge.com)
** LG Electronics Inc.
*** LG Electronics Inc.

under the localized loading.

2. Theoretical Background

A 3-D elasticity solution developed by Pagano and Srinivas and Rao has been specialized to the 2-D analysis of the sandwich beam for the concentrated loading. No restrictions are applied on the material properties and the number of layers for this solution procedure. However, this solution is restricted to the simple supported boundary condition. Those equations and solution procedures are mentioned in the Reference 9.

The importance of this elasticity solution for localized loading was also shown in the comparison of face strain between the elasticity theory and first order shear deformation theory with the variation of loading length ratio.[9] Within the limitations of linear elasticity theory, this 2-D elasticity solution adapted by authors seems to give important insight on the mechanical behavior of sandwich beam for concentrated loading.

3. Experimental

Two kinds densities of polyurethane foam (160 and 320 kg/m^3) with 3.18 and 6.35 mm thickness were chosen as a core layer and $[0_2/90_2]_s$ AS4/3501-6 carbon/epoxy was used for each face. Both face layer and core layer were bonded by using Hysol EA 9309NA for 24 hrs at room temperature. The sample dimension is 25.4 mm in width by 203 mm in length. The span length of 3-point bending test is 152.4 mm and the supporter and of loading pin had a diameter of 6.35 mm

4. Effect of Core and Face Properties

The role of the core layer in the sandwich beam is to sustain the both face layers and carries shear loads from the concentrated loads. Besides this conceptual fact, it is widely known that core densities and core thicknesses are important parameters to take an effect on the mechanical behavior of the sandwich structure.[2]

Another important layer in the sandwich structure is face layer, which is supposed to support the external loads. The thickness ratio of the face layers in the sandwich structures is considered an important parameter in the design procedure. The effects of core density and face thickness ratio will be followed with the experimental results of 3-point bending test.

4.1 Effect of Core density

The experimental yield loads are compared with the predicted failure loads of the elasticity solution in Fig.1. The dominating failure mode was obtained on the basis of three failure modes, which are compressive strain face failure, core shear failure and compression failure in core from the experimental observation. Face failure assumed to be occurred if the critical compressive strain reaches a value of 1.4 % for the AS4 carbon fiber. Core failures in shear or compression assumed to be occurred that the maximum shear or compressive stress in core reaches its yield strength. The failure loads are taken by the failure mode with the lowest yield load.

The theoretical prediction of the elasticity solution shows good agreements with the experimental yield loads in Fig.1. At the constant beam mass with $[0_2/90_2]_s$ face layers, the relative optimized yield load can be obtained at 560 kg/m^3 and the corresponding core thickness will be obtained from the calculation.

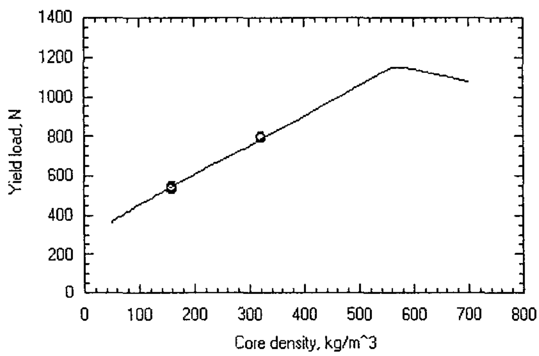


Fig. 1 The variation of yield loads of $[0_2/90_2]_s$ equal face thickness sandwich beams with core densities. (Experimental yield loads of 160 kg/m^3, 6.35 mm and 320 kg/m^3, 3.175 mm core sandwich beams were added.)

4.2 Effect of Face thickness ratio

The effect of different face thickness ratio is investigated at the constant beam mass. The yield loads seems to be controlled by core failure in compression and core shear failure mode. Experimental yield loads are agreed well with the theoretical predicted failure loads in Fig.2.

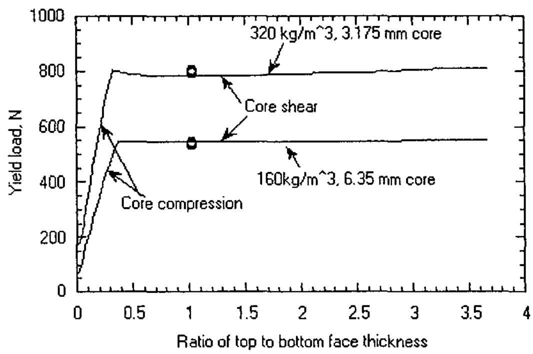


Fig. 2 The comparison of experimental yield loads of 160 kg/m^3, 6.35 mm and 320 kg/m^3, 3.175 mm core sandwich beams with different ratio of $[0_2/90_2]_2$ faces with the prediction of elasticity analysis.

5. The influence of core density and face thickness ratio

It may be necessary to find core densities and face thickness ratios corresponding to optimum condition for strength. The influences of the variables on the failure loads of optimized and off-optimized sandwich beams will be worthy to investigate.

5.1 Influence of Core density

An optimization of the beam with the respect to the core density is pursued with the assumed face mass and an assumed value of the core mass relative to the mass of the two faces and gives the true optimum core density at the intersection point of the three failure modes.

As an example, the optimization procedure is applied for $[0_2/90_2]_s$ equal faces sandwich beam in Fig.3. The true optimum core density is 456 kg/m^3 with the 6.91 mm core thickness. For the equal $[0_2/90_2]_s$ faces, optimum ratio of core mass to face mass is 96.1 %. It seems that the ratio of the core mass to face mass is varied with the mass of the beams

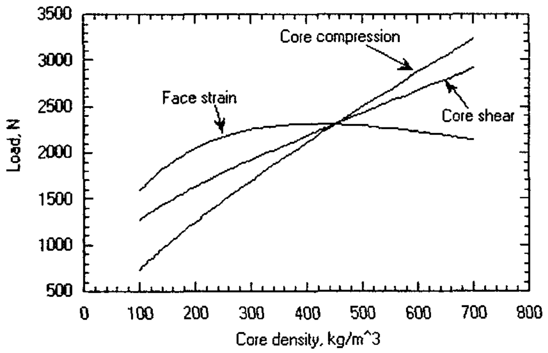


Fig. 3. Predicted yield load for example beam. The intersection of the three failure criteria gives a true optimum design for concentrated loading, which occurs for this example at a core density of 456 kg/m^3.

The true optimum core densities for the strength to weight and for stiffness are compared, indicating that the optimum core density for strength is higher than that for the stiffness under the concentrated loading condition, as shown in Fig.4. Two different ratios of loading length to beam length (0.0045 and 0.045) were chosen. The optimum condition for 0.0045 loading length ratio is 456 kg/m3 core density with core thickness of 6.91 mm, and that for 0.045 mm loading length ratio is 603.kg/m3 core density with core thickness of 8.33 mm. As it was seen in Fig.4, the corresponding optimum core density at loading length ratios of 0.045 is higher than that of loading length ratio of 0.0045. An optimum core density for stiffness also requires the higher density as the loading length ratio is varied from 0.0045 to 0.045. The optimum core density for strength is just higher than about 35 % with the increase of loading length of 10 times, while the optimum core density for stiffness is varied to higher value by 20 %.

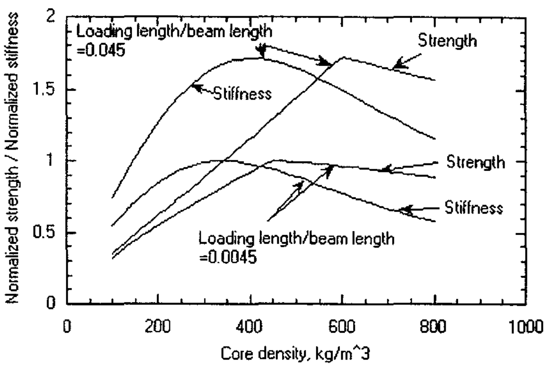


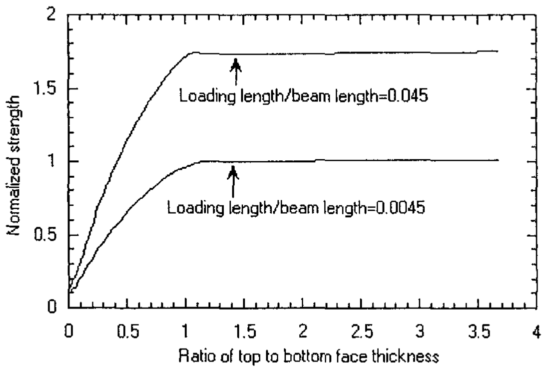
Fig. 4. Predicted effect of varying the core density at different loading lengths. Faces are 8 plies of each of AS4/3501-6, and constant core weight of 160 kg/m^3, 6.35 mm. Strength is normalized to 2278 N, and stiffness to 479 N/mm.

5.2 Influence of Face thickness ratio

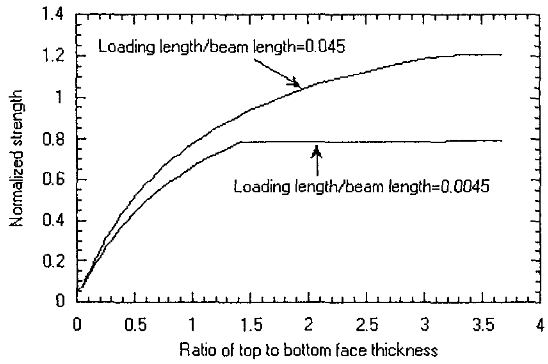
As shown in the Reference [9], the elasticity solution was so effective to predict the strain concentration in the neighborhood of loading region due to the localized loading. The effect of unequal face thickness for the off-optimized and optimized sandwich beam could be important to affect the failure loads of sandwich beam.

At the optimum conditions for the strength at the corresponding loading lengths ratio, the effect of increasing the thickness of loaded face was shown in Fig.5a at the total 16 ply face thickness. The strength at the optimum condition is not much improved with the thicker top (loaded) face thickness with respect to bottom face.

To investigate the effect of unequal face thickness in the case of the off-optimized sandwich beam, the strength of the sandwich beams with the core density of 260 kg/m^3, keeping the constant core mass of the optimum condition in Fig.5a for each loading length ratio, is investigated with the ratio of top to bottom face thickness in the Fig. 5b. The thicker loaded face thickness to the unloaded face for the off-optimized sandwich beam was so effective in the improvement of the strength for a give weight.



a) Optimized sandwich beam for loading length ratio of 0.0045(456 kg/m3, 6.91mm core) and of 0.045(603 kg/m^3, 8.33 mm core).



b) Off-optimized sandwich beam for loading length of 0.045(260 kg/m^3, 12.06 mm core) and of 0.045(260 kg/m^3, 19.35 mm core).

Fig. 5. An effect of unequal face thickness in the optimized and off-optimized sandwich beams at the two different concentrated loading lengths. Strength is normalized to 2278 N.

6. Summary and Conclusions

The influences of core density and face thickness ratio on the failure loads of sandwich beams under the concentrated loads are discussed with the 2-D elasticity analysis. The experimental yield loads show good agreements with the predicted failure loads. The reasonable selection of core density and face thickness ratio could result to the optimum strength of sandwich beams at the localized loading length. When the sandwich beam is designed for the strength to weight under the concentrated loading condition, the effect of both core density and face thickness ratio on the failure loads should be considered to satisfy for the structural requirements.

References

1. Olsson, K.A.,2000, "Sandwich Structures for Naval Ships: Design and Experience," in Mechanics of Sandwich Structures, Proc. ASME Ad Vol. 62, AMD Vol.245, Y.D.S. Rajapakse et al., Ed. 1-9.
2. Gibson,L.J., 1984, "Optimization of Stiffness in Sandwich Beams with Rigid Foam Cores,' Mat. Sci. Eng., 67:125-135.
3. Frostig, Y., et al, 1992, "High Order Theory for Sandwich Beam Behavior with Transversely Flexible Core," J. Eng. Mech.,118:1026-1043.
4. Frostig, Y., 1993, "On Stress Concentration in the Bending of Sandwich Beams with Transversely Flexible Core," Composite Structures, 24:161-169.
5. Frostig, 1993, "High Order Behavior of Sandwich Beams with Flexible Core and Transversely Diagram," J. ASCE, EM Div, 119:955-972.
6. Pagano, N.J., 1970, "Exact Solutions For Rectangular Bidirectional Composites and Sandwich Plates," J. of Composite Materials, 4:20-34.
7. Kim, J. and Swanson, S.R., 2001, "Design of Sandwich Structures For Concentrated Loading," Composite Structures, 52:365-373.
8. Gibson, L.J. and Ashby, M.F., 1997, Cellular Solid, Structures and Properties, 2nd Ed., Cambridge: Cambridge University Press.
9. Swanson, S.R. and Kim, J., "Optimization of Sandwich Beams for Concentrated Loads," accepted for publication in J. Sandwich Structures and Materials.