Analytical prediction of bending stiffness of honeycomb sandwich panels bonded adhesively

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ABSTRACT

Bending stiffness of honeycomb sandwich panel (HSP), which are bonded adhesively, is investigated considering variations in adhesive modulus with temperature. HSP, which is composed of face sheets and honeycomb core bonded with second generation acrylic adhesive (SGA), is taken into account. Because an adhesive modulus of the SGA depends highly on the temperature, the bending stiffness of the HSP decreases with increasing the temperature. It is important to clarify the effect of the temperature on the bending stiffness in terms of safety design of products using the HSP. Therefore, softening of the SGA on the HSP has to be considered for the discussion of the stiffness of the HSP. In this research, the bending stiffness of the HSP is obtained from finite element analysis (FEA) results of three point bending test considering catenary shape of the adhesive. The tendency of the bending stiffness against the adhesive modulus is discussed with various dimensional ratios.

KEY WORDS: Second generation acrylic adhesive; SGA; Honeycomb sandwich panel; Young's modulus; Heating;

1. Introduction

Honeycomb sandwich panel (HSP) is a sandwich structured composite material consisting of a honeycomb core and face sheets. The HSP has a potential to combine increasing of a bending stiffness and weight saving. Therefore, it has been used in crafts. In order to adhere the honeycomb core to the face sheets, epoxy adhesive films have been widely used. Therefore, the HSP has high strength at joining area and high residence of heat. Autoclave process is required, however, it is difficult to increase productivity at the same time as cost saving.

Since a second-generation acrylic adhesive (SGA) was invented, it has been used as a structural adhesive. It cures very fast, it is excellent in oily surface bonding, impact resistance and durability. It also has high strength in peeling and shear. Because it cures very fast and no autoclave treatment is required, high productivity and cost saving can be expected. Therefore, adoption of the SGA into the bonding of the honeycomb core to the face sheets of the HSP can lead to the usage in a wide range of applications, such as elevators and automobiles. The SGA, however, generally have lower heat resistance property than epoxy adhesives [1]. Therefore, the decrease of the bending stiffness of the HSP is expected at high temperature when using the SGA. In order to apply the HSP bonded with the SGA into commercial products, it would be very important to understand the effect of temperature on the bending stiffness of the HSP.

Though the bending stiffness of the HSP has been widely studied numerically and experimentally [2-5], material properties of the adhesive are considered as constant. It would be very suitable when the epoxy adhesives are used. But when the SGA is used, the change of the Young's modulus of the adhesive against the temperature is not negligible. In this research, numerical model of the HSP for three point bending test, which considers the adhesive part, is introduced and the effect of the temperature on the bending stiffness of the HSP is discussed.

2. Model

A honeycomb sandwich panel is composed of three parts, a honeycomb core, face sheets, and adhesive fillets. The core and the sheets are consist of aluminum alloy A5052. As for the adhesive, a second generation acrylic adhesive with the Young's modulus as 750 MPa (at 24 °C) and 5.84 MPa (at 80 °C) is used. In the finite element analysis (FEA), Abaqus ver. 6.12-3 was used. From the cross section observation of the adhesive part of the HSP specimens, the shape of the adhesive fillet is determined as catenary (See Fig. 1). Increment time and time period are set as 0.01 s and 1 s for the simulation condition. Maximum applied load at the center of the specimen was set as 100N.

3. Results and Discussion

Relation between applied load and displacement at the center of the specimen is shown in Fig. 2 with analytical results for dashed lines. In Fig. 2, experimental results, test speed set as 2 mm/min, are also plotted.
Because of the softening of the SGA at high temperature, the elastic region of the SGA at 80 °C is much smaller than that at 24 °C. As shown in Fig. 2, the load of elastic analysis and that of elasto-plastic analysis at 24 °C are almost overlapping each other, and they linearly increase against the displacement. On the other hand, at 80 °C, there exists difference between them. Because the experimental result at 80 °C is in good agreement with the result of the elasto-plastic analysis, it can be said that the SGA adhesive plastically deformed when applying 100 N load at 80 °C.
Numerically obtained bending stiffness of the HSP was 6.40 kNm at 24 °C and 1.05 kNm at 80 °C. Glass transition temperature of the SGA adhesive is lower than 80 °C, and so the Young's modulus dramatically decreases when heating the HSP to 80 °C. Because the Young's modulus of the aluminum alloy does not change as much as the one of the SGA, the change of the Young's modulus of the SGA adhesive would be the major reason of the decrease of the bending stiffness. Therefore, it is very important to introduce the adhesive fillet part into the FEA for the discussion of the HSP softening by the heating.
In the proposed numerical model, it is possible to obtain the bending stiffness of the HSP with arbitrary Young's modulus of the SGA. The bending stiffness increases with increasing the Young's modulus, and converges to a certain value, which occurs when Young's modulus is over about 1 GPa. Increasing the Young's modulus at high temperature to more than 1 GPa would be one of the solution to decrease the effect of the heating on the bending stiffness.
From the results of the bending stiffness with several different dimensions, it is revealed that the thickness and the core density, which can be determined by wall thickness and edge breadth, have a potential to increase the bending stiffness at high temperature condition, i.e. small Young's modulus.

4. Conclusion

Bending stiffness of the honeycomb sandwich panel has been analytically investigated using finite element methods and discussed with experimental results. By introducing adhesive fillet part in the analysis, it becomes available to discuss the effect of the Young's modulus of the adhesive on the bending stiffness of the honeycomb sandwich panel. When the temperature is higher than glass transition temperature, elastio-plastic analysis should be required. It also has been suggested that the Young's modulus of the adhesive has a strong influence on the bending stiffness only when it is smaller than a certain value.

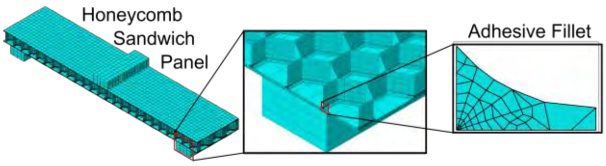

Figure 1. Mesh of the honeycomb sandwich panel model

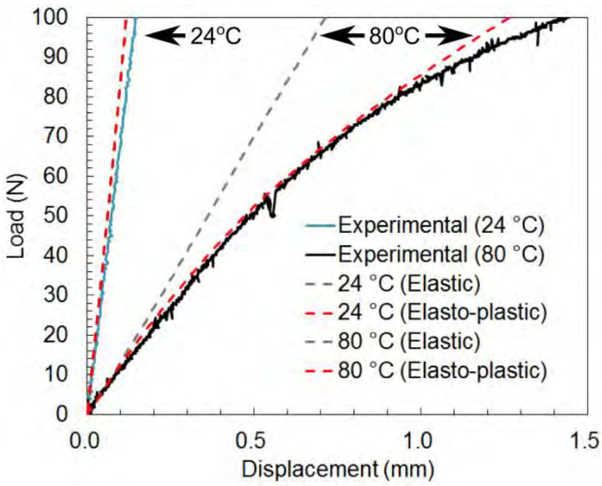

Figure 2. Relation between applied load and the displacement at the center of the honeycomb sandwich panel for three point bending test

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