Effect of Debonding on Stiffness and Long-term Creep of Sandwich panels

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Abstract. The main objective of this study was to analyze the effect of debonding on the stiffness and long-term creep of sandwich panel. Sandwich panel is made of thermoplastic core which is viscoelastic in nature and debonding is the major failure mode of the sandwich panel. Sandwich beams were made of different types of materials and the different materials have different properties. Numerical modeling of sandwich beam with aluminium face sheet and polypropylene core is done. Analysis was performed by using ANSYS software and the element used in the modeling is SHELL181. Four-point load configuration was created for the model with loading of 60 % of core shear strength according to McCallum (2012) and the model were subjected to static deflection. Static deflection results were compared with experimental and theoretical results and stiffness of deboned sandwich beam was evaluated. Primary and Secondary creep was evaluated in ANSYS by using Time hardening and the Norton equations to the propylene core and Burger model was used to fit with the secondary creep of the bonded sandwich beam. The primary and the secondary creep of bonded and the deboned sandwich beams were compared and long-term creep of deboned sandwich beam was determined.

1. Introduction

Sandwich panels are made up of two thin, strong face materials bonded to a low-density core. Sandwich panels have a high strength to weight ratio and a high stiffness to weight ratio due to these advantages, they are used in construction industry, aerospace, naval etc., they are cost effective compared to other composite structures. Because sandwich panels are made of two different materials debonding occurs at the interface of face sheet/core. Effect of debonding on stiffness and long-term creep of sandwich panels are examined.

Sandwich panels are made of thermoplastic core. When the sandwich panel is loaded for a longer period this thermoplastic core exhibits creep behavior. Creep is mainly caused in viscoelastic materials in three stages that are Primary, secondary and tertiary stage. In the initial stage which is known as primary stage the strain rate decreases with increase in time and there is a linear strain in the secondary stage whereas in tertiary stage there is an increase in strain rate and non-linear. Gibson and Huang (1990) conducted test on polymer core sandwich panels and creep compliance is calculated on the material and the creep behavior is studied with linear viscoelastic model. Buket Okutan Baba and Srinivasa Thoppul (2010) performed a test on sandwich panel with four-point loading and found that due to prolonged loading there is a visible damage with the crushing of skin at the loading points and the creep of the sandwich panel increases with the decrease in the stiffness and corresponding slope of load-displacement curve reduces with upper debonded.

In this paper stiffness and long-term creep of deboned and normal sandwich panels were compared. Assuming the skin does not creep and the core creeps. Creep of sandwich panel is studied using Burger model. ANSYS software was used to study the creep and stiffness behavior of sandwich panels numerically.
2. Methodology

2.1 Numerical modelling in ANSYS.

In this study, ANSYS was used in modeling the sandwich beam with aluminum face sheets and polypropylene core to investigate the stiffness and long-term creep behavior of debonded sandwich beams subjected to four-point loading.

SHELL 181 element was used in modeling the sandwich beam. It helps in solving the finite element analysis of structural engineering related problems. It helps in modeling the sandwich beams with composite materials and evaluating the creep strain rate and maximum deflection of bonded and debonded sandwich panels using different shell elements and the solid elements were used in modeling 3D.

2.2 Four-point load configuration

The loading was modeled in ANSYS based on thesis of McCallum (2012) experiment for evaluating the results for deflection and creep of bonded sandwich panel. The primary and secondary creep is considered in the core as it has the constant bending moment. The supports are provided at 25mm at each end. The load is considered at one fourth of the total length of sandwich beam applied load is 60% of ultimate load of 40mm Aluminum sandwich panel provided in McCallum (2012) thesis.

2.3 Theoretically predicting the deflection and creep of sandwich beam

According to classical beam theory by (Zenkert 1995) shear deformation is considered to be negligible as the beams are stiff in shear and only transverse shear deformation is taken into consideration. In the sandwich beam, the shear stiffness is low because of that this deformation component is included bending deformation.

According to (Zenkert 1995) sandwich panels behave like an I-beam and the bending deflection is transferred at mid span can be calculated using

\[ w(L_2/2) = \frac{P(L_2 - L_1)(2L_2^2 + 2L_1L_2 - L_1^2)}{48D} + \frac{P(L_2 - L_1)}{2S} \]

\[ S \approx \frac{G_c d^2}{t_c} \]

Where

- \( L_2 \) = distance between supports (mm)
- \( L_1 \) = distance between the loads (mm)
- \( P \) = Unit load applied on the beam (N/mm)
- \( D \) = Bending stiffness of the skin (Nmm)
- \( E_r \) = Elastic modulus of skin (N/mm²)
- \( t_r \) = thickness of flange.
- \( d \) = distance between centroid of faces.
- \( G_c \) = shear modulus of Core (MPa)
- \( d \) = distance between the centroid of sandwich panel to skin material (mm)
- \( t_c \) = thickness of core (mm)

By using Burger model secondary creep of bonded sandwich beam was verified against the modeling results.
3. Results and discussion

3.1 ANSYS modelling

ANSYS software was used in analyzing the effect of debonding on stiffness and long-term creep of sandwich panels. SHELL 181 element was used for modeling as it is capable of modeling composites in the form of layered elements. The model of sandwich panel made of SHELL 181 is loaded with 60% of core shear strength. The comparison of static deflection of the model with experimental deflection was done from McCullum (2012) experiment. The experiment value of the sandwich panel was found to be 3.698mm and the ANSYS result on deflection was 3.8536mm. The percentage error between the experimental and the ANSYS results was 4.12%.

The maximum deflection of the debonded sandwich panel was 4.2559mm, when compared with the bonded sandwich panel the maximum deflection of bonded sandwich panel was 3.856mm. The percentage difference between the maximum deflection of bonded sandwich panel and the debonded sandwich panel was 9.92%.

![Figure 1: Static Deflection](image1)

![Figure 2: Debonded Sandwich beam](image2)

3.2 Discussion:

Figure 2 represents the debonded sandwich beam. When the sandwich panel was loaded at 60% of its failure load from McCallum (2012). To observe the maximum deflection of the debonded sandwich beam, debonding was created at the middle of sandwich beam using frictional contact of 0.2. Maximum deflection observed in the middle and the minimum deflection is observed at the debonded face sheets. Stiffness is the resistance towards deformation.

From theoretical investigation the bonded sandwich panel has high stiffness compared to debonded sandwich panel. According to the experimental investigation of Barbosa (2010) on face/core debond of the four-point load concluded that the presence of debond causes decrease in the stiffness of sandwich beam.

3.3 Creep of sandwich beam results:
Primary creep and secondary creep of the sandwich beam was modeled in ANSYS using the time hardening equation and sandwich beam loaded with the 60 percent of the shear strength of the core from McCullum (2012) is 1377.22 KN. The constants used in the equation from the experiment done on polypropylene (Dropik et al. 2002). The primary creep was calculated for 18 days for reference to obtain the primary creep curve and the graph was plotted between creep strain vs. time.

\[ \varepsilon = C_4 \sigma^p \cdot e^{-\frac{\sigma}{C_1}} \cdot t^{-0.826} \]

Here, the constant \( C_4 \) is 0.

**Figure 3:** Primary Creep of bonded Sandwich beam

Secondary creep of sandwich beam was modeled in ANSYS by using Norton equation which was present in ANSYS for calculating the secondary creep. The secondary creep was plotted for 5 days as the secondary slope was same throughout the time.

**Figure 4:** Primary Creep of debonded Sandwich beam

**Figure 5:** Secondary Creep of bonded sandwich beam
The primary creep of bonded and debonded sandwich panels were plotted for 18 days to observe the slope of how the primary creep varies at maximum deflection. We can see from graph the primary creep slightly increases at first and has the same slope after 12 days.

The primary creep of debonded sandwich beam is expected to have more slope than the bonded sandwich beam but probably due to localized indentation, load is not transferred to the whole beam. In case of bonded sandwich beam load is properly distributed. Form fig 4 we can observe that the maximum load was transferred to the face of the sandwich beam and it resists the creep of the core. The creep deflection for a debonded panel is expected to be higher if the panel is heavily loaded (close to the failure load) or the load is acting for a long time.
The secondary creep of bonded and the debonded sandwich beams were calculated for 5 days as the secondary creep has the constant creep rate throughout the time. The secondary creep was assumed to be caused after the primary creep.

Secondary creep of sandwich beams was modeled with the help of Norton equation in ANSYS and the graphs were plotted for the secondary creep of bonded and the debonded sandwich beam. We can observe that there is a less slope in the debonded sandwich beam due to the debonding caused in the sandwich beam, as discussed earlier it might be because of local indentation the face sheets carrying the maximum load the slope of debonded sandwich beam is less.

Sandwich beam is loaded under 60 percent of shear strength from McCallum (2012) Burger model does not coincide with the secondary creep the slope of these two has 13 % difference which might be some issues with the constants used in the Norton equation while modeling the secondary creep of sandwich beam.

3.4 Problems faced in Creep Analysis

It was taken long time for about 9 hours for generation of results of model and while running the analysis for results there was a warning indicates that the polypropylene has the negative creep constant. The creep constants which were used in the analysis were from the experiment conducted by Barbosa (2014). Modeling was tried in different ways of obtaining solution within short period by converting the model into symmetric about xy and yz plane. Whereby converting the model into symmetry, the solution of the model is quick, but we were unable to observe the clear deflected shapes of sandwich beam. Several ways were used to create the debonding of sandwich beam. Contact debonding was used to create debonding of sandwich beam but was unable to create at the desired places.

4. Conclusions

The objective of this study was to study how the stiffness and long-term creep of the sandwich panel was affected due to the debonding which was caused in the sandwich beam when the flexural loads were acted on the sandwich beam. Thermoplastic (polypropylene) core was used in modeling the sandwich panel. Researchers from the past indicate that the sandwich panels with thermoplastic core are prone to exhibit creep behavior even in a smaller time frame. Creep occurs in three stages: primary, secondary and tertiary stages. In the initial stage which is known as primary stage the strain rate decreases with increase in time and there is a linear strain rate in the secondary stage whereas in tertiary stage there is an increase in strain rate and non-linear. The failure of the sandwich panel occurs in the tertiary stage.

Numerically the static deflection of the model was validated and has the difference of 4.12% with the experimental value from the thesis of McCallum (2012) and justified as the model was performing well under static loading. Face sheets of sandwich panel were separated by viscoelastic core due to that when the load was applied for longer period debonding occurred. Stiffness and Long-term creep of the debonded sandwich panels were compared with the bonded sandwich panel. From the simulation, we have observed that the stiffness of the bonded sandwich beam was higher than the debonded sandwich beam and the results of the model was according to theoretical and experimental results performed by McCallum (2012).

Primary creep of bonded sandwich beam has slightly higher (25%) than the debonded sandwich
beam which was perhaps caused by the localized indentation of the debonded sandwich beam with the maximum load was carried by the face sheet. Due to the maximum load carried by the face sheet, in the secondary creep strain rate of the bonded sandwich beam is higher than the debonded sandwich beam. To study the creep behavior of the bonded sandwich beam, hence Burger model was used in secondary creep of bonded sandwich beam. There was a 13% variation in the burger model of the secondary creep in bonded sandwich beam. We were mainly concerned with secondary creep because it has more and more creep due to this the accumulation of damage it goes to the tertiary stage, so it is critical. The possible reasons of the debonded sandwich beam do not have the higher slope than the bonded sandwich beam was due to the localized indentation or due to the error in using frictional contact.

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