Numerical Modeling and Experimental Investigation of the Failure Modes of the Cellular Foam Sandwich Structures

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Abstract— The use of sandwich materials can lead to economical advantages in many applications by means of weight reduction. In spite of its large demand, its distribution in the field of mechanical engineering is constrained due to unsolved problems in the connection technology and uncertainties in the mechanics of such structures. Hence, in this field, there exists a demand for the support of engineers who facilitate the design of sandwich structures. This paper describes the methods utilizing strategies for 3D-modeling and the simulation of plating by using the commercial FEM-System ALGOR, which interface with the CAD-system. The four-point bending test was performed in order to determine the load-deflection behaviour of a sandwich plate under static loading conditions. In the experimental part of the work, the simulated loading case was tested repetitively on the servo-hydraulic machine. The linear elastic behaviour and the different failure of sandwich plate conditions were investigated as to the testing environment. The results obtained with the association of the FEM criteria, were compared to the analytical and experimental results. The analytical data reflects that the computed compressive stress values facilitate a good working agreement with the analytical results. The value of the shear stresses from the simulation was approximately 0.26 MPa, while according to the empirical formulas by Zenkert, the shear stress was amounts has to calculated to be 0.29 MPa. The results showed, that the core shear failure took place in the same regions, which were a good agreement between the FEM and experimental data.

Keywords—Sandwich material, modelling and simulation, FEM-Software, four-point bending, shear stress

1. INTRODUCTION

A sandwich material is a composite material. A Sandwich structure usually consists of two thin, stiff, strong sheets of composite material separated by a relatively soft core material [1,2]. Faces and core are then bonded together to form an efficient load carrying assembly. Lightweight sandwich constructions are used to increase the specific stiffness, which formulate the strengthening of structures for functional and economical reasons [3]. The face carries bending moments as tensile and compressive stresses, whereas the core carries transverse forces as well as shear stresses [4].

The principle of sandwich construction is well established in all fields of aerospace technology. Nowadays, sandwich panels can be found in many other technological fields such as in high-speed ferries, high-speed passenger trains, marine industry, building industry or automotive applications. Especially in the naval industry, there is a strong trend to use sandwich shells in the construction of ship hulls. Other innovative examples include civil engineering structures, such as highway bridge decks [5,6]

An effective understanding of the sandwich mechanics is necessary for effective design. Designers of sandwich panels must ensure that all potential failure modes are consider in their analysis. The Finite Element Method (FEM) is common and most effective tool for structural analysis of sandwich construction.

In the frame work of this paper, modelling, simulation and experimental verification of PUR-foam core with steel faces for static loading conditions are considered. The faces and core materials were assumed to be linear-elastic and isotropic material. For this purpose a computer model based on the finite element method is developed to simulate the four point bending. The failure modes of a sandwich plates are carried out using the commercial finite element code ALGOR V18. The models are developed by a three-dimensional finite element model. These models refer to the analysis performed using solid elements and plate elements.

The four-point bending test is performed in order to determine the failure modes behaviour of a sandwich plate under static loading. The sandwich theory presented by Allen and Zenkert, [1,7] is used to compute the behaviour of sandwich plate.

The aim of this work is to analyse the mechanical behaviour of sandwich plate by using FEM, in order to predict failure modes of such structures for design applications. The obtained results concur excellent with the experiments and the analytical computations.

2. FINITE ELEMENT MODEL DEVELOPMENT

The sandwich material dimensions are taken in accordance with DIN 53293 [8] (200x1440x60 mm.).

The model here was created using Pro/ENGINEER[T] (Figure 1). This geometry information was transferred to the FEM-Software, using the standard Initial Graphics Exchange Specification format file (IGES).

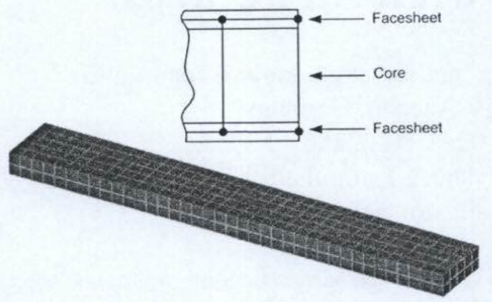

Fig.1 Model of the Sandwich by ALGOR [9]

The sandwich model consists of solid element (BRICK) and plate element (PLATE). The solid element is used for core material and the plate element is used for face materials. The nodal displacement of brick element and plate element are shared at the same position. After meshing, the face material and core material also shared together. Contact pair should be defined between the face sheet and the core. The type of contact, "Bonded" was used for this model. The two surfaces were found to be in perfect contact throughout the analysis. It was found that when a node on one surface deflects, the node on the adjoining surface will deflect the same amount in the same direction.

3. EXPERIMENTAL

3.1 Step and Test Equipment

The sandwich plate specimens were tested with 3 kN Hydraulic press controlled by DYNA-MESS[TM] controller. The controller has been set up for a load rate of 0.015 kN/s. Each specimen has been placed in the test apparatus as shown in Figure 2. The cylindrical loading and support rollers, made of steel and having a diameter of 60 mm, are placed such that the effective beam span (displacement between support rollers) is 1,200 mm, and the loading span (distance between loading rollers) is 600 mm. A linear varying displacement transducer (LVDT) is placed at the midspan of the sandwich plate and is connected to the controller to record displacements.

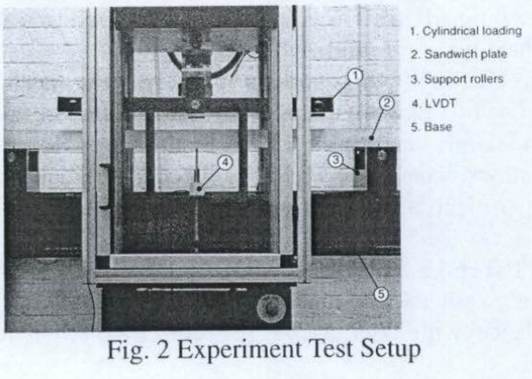

Fig. 2 Experiment Test Setup

3.2 Experimental Procedure

In this apparatus the upper (loading) rollers are moved downward against the sandwich specimen. The specimen is loaded at the rate of 0.015 kN/s until failure. The displacement of the midspan of the sandwich plate is monitored during the test using the LVDT described above. This displacement represents the deflection of sandwich plate as to the vertical direction. The applied load and elapsed time was recorded by a plotter integrated with DYNA-MESS controller and by a digital data acquisition system. This digital data is used for the analytical assessment.

4. RESULT AND DISCUSSION

4.1 Facesheet Wrinkling

The failure of the sandwich plate was found about 3,000 N at the load transmission. The failure occurs spontaneously, thus the local deformation would be recognizable. Besides the permanent deformation of the facesheet, the combination with a locally crushed core (Figure 3) does not occur at the support loads, although the same force is transmitted into the facesheet. This failure formulates an unstable buckling of the facesheet under the longitudinal compressive load in combination with a compressive failure with the core. It therefore, does not also occur at the support load, where the facesheet will only carry tensile stress in a longitudinal direction.

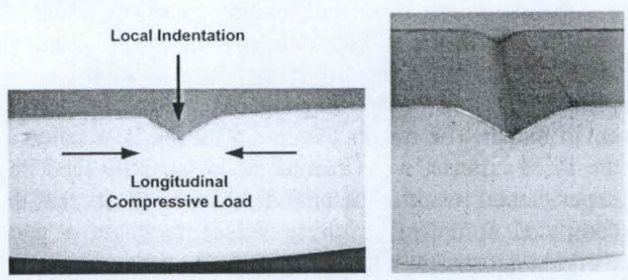

Fig. 3 Facesheet wrinkling

The compressive strength of the core material is calculated by ZENK97 [7] of 0.56 MPa. This value is appropriate for about 20% over the compression stresses of the core, which was determined with the FEM Simulation for the failure load by 3000N of 0.42 MPa, see also Figure 4. Since a detailed view of the FEM simulation of this failure mode and the experimental verification of the compressive strength of the core material can only be accomplished with in the following work environment, the intermediate result can be noted during the linear elastic simulation and the compression stress of the core must be considered. At least in most cases, where this reaches the magnitude of the compressive strength, an individual view of the facesheet wrinkling behaviour under longitudinal compression is recommended to accomplish the desired result.

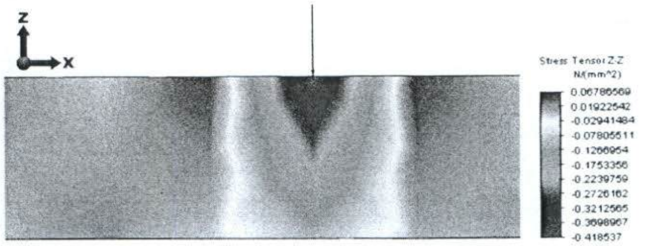

Fig. 4 Compressive stress distribution in core

4.2 Core shear

Sheet metal was reinforced in the areas of the forced application and the outer supports, in order to be able to further examine the experimental failure modes, which prevented the facesheet wrinkling. In addition the sheet metals with the thickness of 1.5 mm were glued on the facesheets of the sandwich plate.

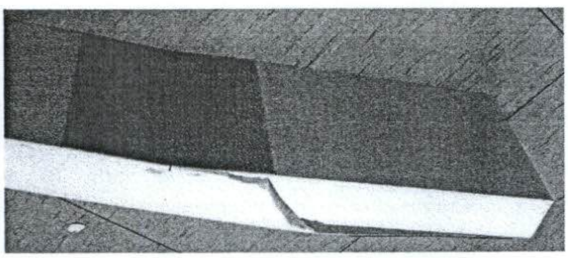

Fig. 5 Core shear failure by 5.5 kN

The experiment confirms this result; a facesheet wrinkling does not occur at the force application. Instead the sandwich specimen fails clearly at the higher load of approximate 5.5 kN by a shear core failure, as seen in Figure 5. This failure occurs, if the shear stress in the core is higher than the shear strength of the core material.

Finally, it was examined whether this material failure can be predicted by the FEM simulation. It is, however, the place which is remarkably noted, but not surprising, as to which the failure appeared. The highest shear stresses occur between the two force application and the support load, as seen in Figure 6. It can see clearly that the shear stress in sandwich plate was small value under the sheet metal.

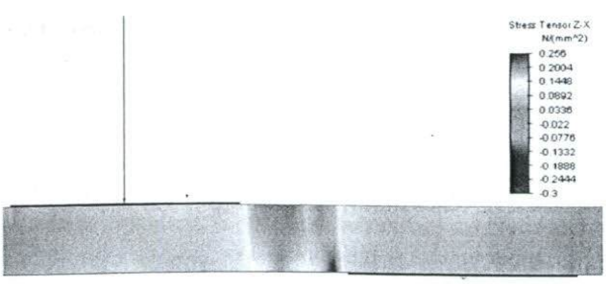

Figure 6. Shear stress distribution in core

The comparison of the shear stress between the simulation and the theoretical analysis by Zenkert at the load case 5.5 KN was carried out. The height of the shear stresses from the simulation was approximate 0.26 MPa, according to the empirical formulas by Zenkert, amounts to 0.29 MPa. The results showed that the agreement between theory and experiment were very good.

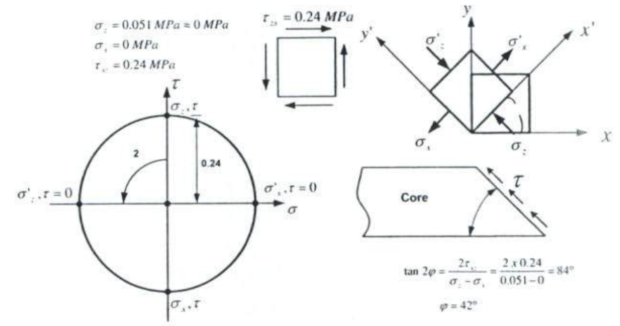

Fig. 7 Analysis of the shear stress angle

The shear stress angle can determined by Morh's Cicle theory. Therefore, the angle of the core shear was 42 degree, as seen in Figure 7.

5. CONCLUSION

This paper gives a guideline to model the sandwich material and to predict the failure modes. The comparison of the computation results are performed, whose results are validated by experiments. The analytical models of failure are useful for sandwich failure modes, the results of the simulation agree very well with sandwich theory. The failure modes of sandwich plate were investigated in order to compare with the FEM results. The experimental results show that the deformations of the sandwich plate in elastic region agrees very well with the FEM results.

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