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New peel stopper concept for sandwich structures

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Abstract

The paper addresses the damage tolerance of sandwich structures, where the prevention and limitation of delamination failure are highly important design issues. Due to the layered composition of sandwich structures, face–core interface delamination is a commonly observed failure mode, often referred to as peeling failure. Peeling between the sandwich face sheets and the core material drastically diminishes the structural integrity of the structure. This paper presents a new peel stopper concept for sandwich structures. Its purpose is to effectively stop the development of debonding/delamination by rerouting the delamination, and to confine it to a predefined zone in the sandwich structure. The suggested design was experimentally tested for different material compositions of sandwich beams subjected to three-point bending loading. For all the tested sandwich configurations the suggested peel stopper was able to stop face–core delamination and to limit the delamination damage to restricted zones.

Keywords: B. Fracture; B. Interface; C. Crack; C. Delamination; C. Sandwich

1. Introduction

Sandwich materials are layered structural components composed of thin strong face layers separated and bonded to light weight core materials. This particular layered composition creates a structural element with a very high bending stiffness to weight ratio as well as bending strength to weight ratio. Sandwich structures are often utilized in the marine, aerospace, train and automotive industries, where low weight is a critical design parameter. Furthermore, large parts of wind turbine blades are made using composite sandwich materials.

The general concept of sandwich structures has been investigated and developed by many researchers over the past 50 years, see for example Zenkert [1,2], Allen [3] and Gay [4]. It is well known that sandwich structures may suffer from sudden failure if the allowable design loads are exceeded. When structures are made of ductile metallic materials, e.g., steel or aluminium, usually they do not fail catastrophically in a sudden way, due to their ability to redistribute the loads by plastic yielding. As opposed to this, composite and sandwich structures often exhibit a more brittle behaviour, and this, together with their inherent layered composition may lead to a sudden and fast failure by delamination (peeling), which occurs without any prior warning. Therefore, the study of initiation, propagation and arrest of delamination failure are issues of extreme importance for modern sandwich structures.

Failure phenomena related to sandwich structures have been studied intensely by various researchers. Zenkert et al. have studied failure in foam cored sandwich panels with and without initial debonds [5–8]. They examined sandwich beams subjected to three-point bending loading under quasi-static and fatigue loading conditions. For the majority of the tested configurations face–core delamination occurred as failure mode. Moreover, in some cases failure initiated in the centre of the core and then kinked toward the face sheets and continued as a delamination along the face–core interfaces.

Failure phenomena in general, and crack tip propagation in particular, in sandwich structures under in-plane

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compression loading have been studied by Carlsson et al. [9–11] among others. Sandwich elements with initial debond imperfections were experimentally studied, and it was concluded that the initial debonds would grow when the load applied to the test specimens exceeded the buckling load of the face sheet (i.e., wrinkling of the sandwich faces). Furthermore, their results stated that larger initial debonds would lower the total buckling strength of the sandwich panel, and that the geometrical shape of the debonded area seems also to have a significant influence on load bearing ability of the sandwich panel.

Bozhevolnaya et al. [12–16] investigated the influence of core junctions on the static and fatigue strength of sandwich beams. It was found that modifications of the geometric shape of a core junction can have a considerable effect on the fatigue life of sandwich structures. Additionally, similar to the studies [5–8] for the case of static and fatigue loading, it was observed that face–core delamination very often was the dominating failure mode, which usually followed shear cracking of the compliant core in the sandwich beam. Core junction failure was further studied for sandwich structures subjected to in-plane tensile loading [17], and it was concluded that failure generally initiated in the vicinity of the core junction, and that final failure occurred as tensile face failure.

According to the previous works cited above, a commonly observed failure phenomenon for sandwich structures is face–core delamination, which usually follows various types of locally induced damages in the sandwich core and/or in the vicinity of sandwich sub-structures like core joints, inserts or edge stiffeners. This failure mode is also referred to as face sheet peeling. Several techniques for improving the peeling strength of face-core interfaces are known today. For example, Grenestedt [18] suggested a new peel stopping manufacturing technique. The basic principle of this technique is that the debonded face sheets are able to be separated from the structure in order to arrest delamination growth beyond the implemented peel stoppers [19]. This method also implies that the sandwich structure looses a huge part of its overall bending stiffness and in-plane tensile strength, as part of the face sheets simply peels of. Accordingly, the advantages of the structural sandwich concept no longer exist or are significantly diminished.

Another approach to arrest face sheet delamination is to stitch the face sheets together [20–22]. This method creates a sandwich panel with extraordinary high transverse stiffness and strength. Moreover, the shear properties can also be improved if the stitching angle is inclined 45° with respect to the normal plane of the sandwich panel. The method is very effective when applying it to monolithic composite laminates, but rather tedious and design restrictive in sandwich applications. Moreover, manufacturing complexities and costs are often increased with this method. However, the commercially available sandwich systems X-cor™ and K-cor™ of Albany Engineered Composites [29] belong to this type.

The research presented in this paper concerns the proposal of a new peel stopper design, which effectively prevents peeling of the faces, and limits debonding/delamination to a priori restricted areas of the sandwich component. The design of the new peel stopper is described, and the choice of appropriate peel stopper material is substantiated. The efficiency of the new peel stopper concept is validated by experimental tests with sandwich beams subjected to three-point bending up to the failure.

2. Peel stopper concept

The basic design of the suggested peel stopper is illustrated in Fig. 1. The peel stopper is a sub-structural component embedded into the sandwich panel (like an insert or edge stiffener), and its main purpose is to arrest face–core interface crack propagation by rerouting the crack path into a closed/restricted area of the sandwich panel, thus preventing the spreading of debonding/delamination into the remaining parts of the sandwich structure.

For the present study, the peel stoppers were manufactured from an elasto-plastic material, with elastic properties close to the sandwich core properties. Generally, it is recommended that the material of the peel stopper is chosen to be compliant and with large straining capability (i.e., ductile), and the elastic stiffness of the peel stopper is recommended to be of the same order as the elastic properties of the main sandwich core (or somewhat higher). Good adhesion properties with respect to both the core and the faces are required as well.

The peel stoppers may be mounted into a sandwich panel (e.g., a sandwich beam, plate or shell) together with other sub-structural components like e.g., structural inserts as shown in Fig. 1. Essentially, there are no or only minor

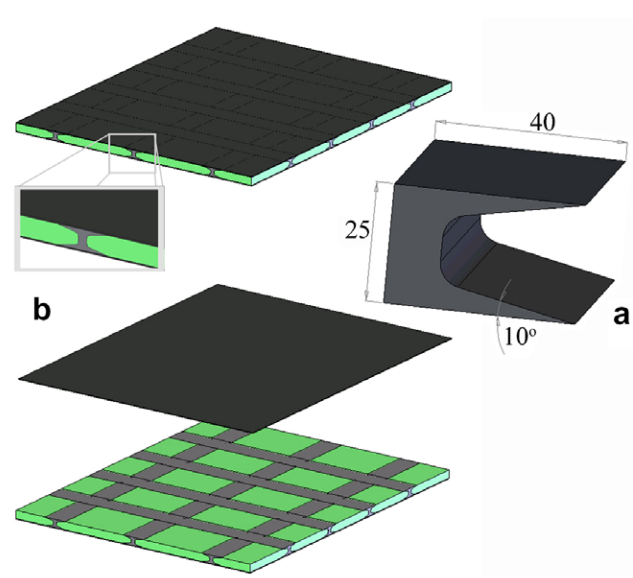

Fig. 1. Proposed design of the peel stopper (a). The case shown displays a crack rerouting angle of 10°. A suggested implementation of the proposed peel stoppers in a sandwich plate is shown in (b). The grid type pattern will confine damage to the grid mesh.