METHODS FOR THE DESIGN AND MANUFACTURING OF TAILORED HONEYCOMB CORES (THC)

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1. INTRODUCTION

Sandwich structures are essential components of modern aircraft structures and are employed in numerous applications due to their excellent lightweight properties [1]. Two thin, rigid cover layers and a core as a spacer form the sandwich composite thus achieving high specific bending stiffnesses. The core of these sandwich elements is mainly made up of geometrically hexagonal cells of the same dimensions, creating honeycomb patterns. For loads, applied perpendicular to the panel plane, the structure is subjected to shear stress [2].

The conventional manufacturing processes consists of the application of parallel adhesive layers at regular intervals onto Nomex paper sheets by rolls, followed by stacking and pressing the individual layers. The stack is then expanded and stabilized with heat. In a resin bath, the expanded honeycomb block is subsequently impregnated, forming a resin layer. The wall thickness can be increased through multiple repetitions. Figure 1 illustrates the whole process. In this way, sandwich cores with uniform mechanical properties across the plate plane can be produced.

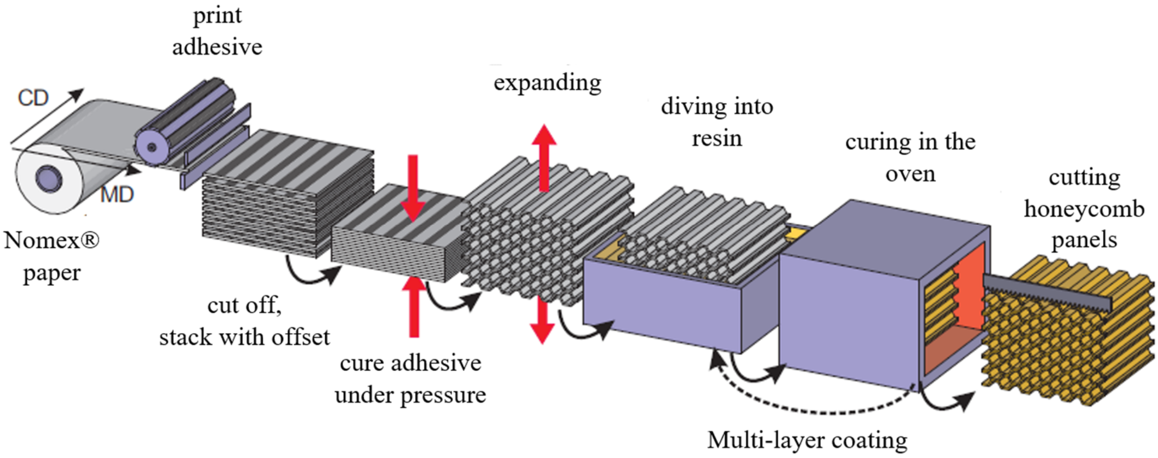

Fig. 1: production process of Nomex® honeycomb sandwich cores [3]

Sandwich elements are subjected to external loads perpendicular to the plane of the plates, with varying intensity and distribution depending on the type and magnitude of the load. As a result, the core is designed according to the highest local load, which reduces the degree of performance.

For applications involving large-scale sandwich structures, the current adjustment methodology using spliced cores with varying properties leads to local stiffness discontinuities and overall increased mass, thereby compromising the structural performance [3]. This is no longer permissible for new sandwich constructions. A load-adaptive design of the honeycomb cores, coupled with an appropriate manufacturing technology, is crucial to overcome these disadvantages and restrictions. Tailored honeycomb cores (THC) are to be developed using known methods and materials for a rapid implementation process.

This research investigates how load-optimized tailored honeycomb cores can be developed and manufactured to meet the specific requirements of aerospace structures. The study presents methods to address these requirements through numerical simulations and experimental analyses.

Component-specific material combinations and cell geometries have been investigated, which can potentially be applied variable, taking into account all boundary conditions. Experimental investigations provide the necessary mechanical properties of core materials, including bio-based materials. Beyond that, highly detailed, parameterized simulation models are being developed to predict the impact of variable material compositions and cell geometries on the structural and manufacturing properties of the sandwich cores. Furthermore, new manufacturing technologies based on the classical expansion process for cell cores are being developed.

2. TAILORED HONEYCOMB CORES

For the implementation of load-adaptive honeycomb cores, three fundamental approaches for load adjustment have been defined. The cell geometry should be capable of varying in terms of its hexagonal cell dimensions. This requires the creation of geometric transition areas for cell structures with different cell widths. Furthermore, flat materials of varying thicknesses and materials can be placed in the stack before the expansion process to allow a use of a multimaterial mix to adapt the locally required properties. Finally, local areas of the core will be coated with varying thicknesses of resin to stabilize the core in the corresponding ranges.

Honeycomb cores, which feature differently dimensioned hexagonal cells in specific areas, can be manufactured in a single step during the expansion process using the developed technology. The geometry of the cell cores remains constant in the direction of the core height. This technology is realized through the sequential application of adhesive at specific lengths and intervals onto the core-forming paper materials. Cell transitions for cell wall length ratios of 1:2 and 1:1.5 in the main core directions and across corner areas have been successfully realized. To illustrate this, figure 1 a) shows the cell wall geometry of a sandwich core, which realizes a transition across the corner from one cell width to another with a transition ratio of 1:2. Hand samples demonstrate the feasibility of the developed concepts as shown for the transition ratio of 1:2 in figure 1 d).

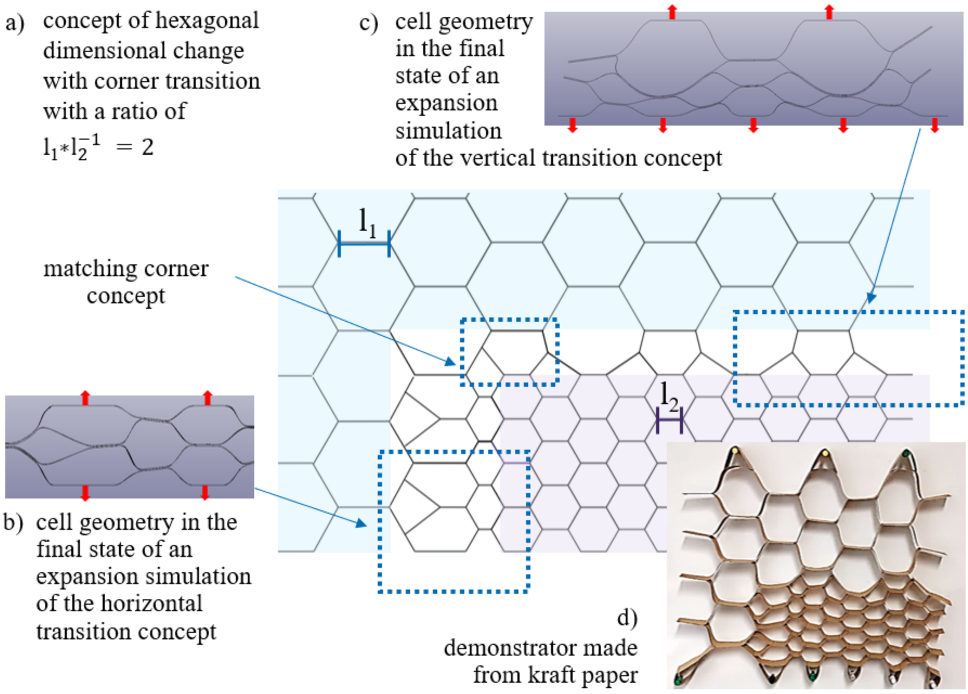

Fig. 2: geometry of a cell transition of an expandable hexagonal honeycomb core in a corner section

The expandable transition concepts and demonstrators are achieved by defining specified sequences of lengths with and without adhesive application. These are applied to the cell wall material layers in the first step of core production, as shown in figure 1. A design tool for calculating the required adhesive sequences for the specific transition sizes has been developed. The sequence and the widths of the adhesive lines were generated by implementing boundary conditions of all closed cell systems in the respective geometrically defined transition regions via systems of equations, ensuring the full expandability of the material stack. Further technically relevant cell transition ratios for aerospace applications can be realized using this tool. Additionally, transitions to non-hexagonal cell areas are planned, enabling the realization of a local bendability of the cell core for the production of partially curved sandwich elements.

Numerical simulations were developed and conducted to predict the expandability. Simulation models for individual cell regions with the developed cell transitions were constructed using shell elements. In these models, the effect of the thin adhesive bond was neglected, thus the interaction between the individual material layers was realized through shared nodes. The model is supported at the lower layer at the corresponding sequential intervals, allowing for lateral contraction during expansion. By applying a predefined displacement rate in the expansion direction, sequential areas of the top layer are loaded, causing the model to expand. The implicit finite element simulations were performed using the direct solver of LS-Dyna over multiple time steps to capture the high degree of nonlinearity in the expansion process. Two examples of the expanded transition geometry are shown in Figure 1 b) and c).

The numeric expansion studies revealed that, for the regular expansion of the structure with varying cell size ranges, adjustments in local bending stiffness are necessary. Influencing parameters for expanding single cells were investigated through numerical simulations. Based on the findings, measures are currently developed to adjust specific sections in terms of their bending stiffness and dimensions, allowing for the manufacturing of a honeycomb core with cells with the same degree of expansion.

The manufacturing of these load-adaptive cores is currently carried out using an automated adhesive application technology with stamps of various widths. This provides an adequate approximation of the established cylinder roller application method used in the industry [5]. Additional methods for applying a heat-resistant two-component epoxy adhesive via nozzles are under investigation.

3. CONCLUSIONS

The research findings provide valuable insights for the production of honeycomb cores with variable mechanical properties. By developing and simulating concepts for honeycomb cell size variations to create load-adaptive tailored sandwich cores, stiffness discontinuities within sandwich structures can be avoided, thereby enhancing the structural integrity of these aerospace components. These results pave the way for future investigations and developments on load-optimized tailored core design, enabling a new generation of aerospace structures with higher efficiency.

With the submitted patent for the "cell structure, method for producing a cell structure, and cell support core", [4] the practical feasibility of these innovative technologies is further secured. The research contributes to addressing both technological and ecological challenges within the aerospace industry, facilitating the development of innovative, high-performance sandwich structures.

ACKNOWLEDGMENTS

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