Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 56 (2014) 327 – 335

Physics Procedia

8th International Conference on Photonic Technologies LANE 2014

Load-dependent Optimization of Honeycombs for Sandwich Components – New Possibilities by Using Additive Layer Manufacturing

Fabian Riss[a,*], Johannes Schilp[a], Gunther Reinhart[a]

[a]*Fraunhofer Institute for Machine Tools and Forming Technologies (IWU) Project Group for Resource-efficient Mechatronic Processing Machines (RMV), Beim Glaspalast 5, 86153 Augsburg, Germany*

Abstract

Due to their feasible geometric complexity, additive layer manufacturing (ALM) processes show a high potential for the production of lightweight components. Therefore, ALM processes enable the realization of bionic-designed components like honeycombs, which are optimized depending upon load and outer boundary conditions. This optimization is based on a closed-loop, three-steps methodology: At first, each honeycomb is conformed to the surface of the part. Secondly, the structure is optimized for lightweight design. It is possible to achieve a homogeneous stress distribution in the part by varying the wall thickness, honeycomb diameter and the amount of honeycombs, depending on the subjected stresses and strains. At last, the functional components like threads or bearing carriers are integrated directly into the honeycomb core. Using all these steps as an iterative process, it is possible to reduce the mass of sandwich components about 50 percent compared to conventional approaches.

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH

Keywords: honeycombs; sandwich components; load-dependency; additive manufacturing;telegraphing-effect, snap-in connections

* Corresponding author. Tel.: +49-821-56-883-97 ; fax: +49-821-56-883-50 .
E-mail address: fabian.riss@iwu.fraunhofer.de

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH
doi:10.1016/j.phpro.2014.08.178

1. Motivation

A great challenge in developing products is the design of light and especially valid products (Henning et Al 2011). Mainly by reasons of increasing the world wide output of CO_2-gas, as well as the shortage of resources lightweight design is becoming an increasingly important topic. According to Klein (2009), lightweight design can be classified as:

- Geometrical lightweight design (e. g. hollow structures)
- Material lightweight design (e. g. fiber reinforced materials)
- Manufacturing lightweight design (e. g. integral and differential design)

The aim of all these lightweight approaches is the reduction of mass in technical products. Applications of lightweight design can be found in accelerated machine components or in transportation systems, in order to reduce acceleration energy or to raise the occupancy load (Degischer et al. 2009; Reinhart et al. 2011).

A simple approach for mass reductions is the application of bionic design principals. That means eliminating material in part areas with no or few load. Cellular, prismatic and sandwich structures are the mostly used bionic design approaches in technical products (Degischer et al. 2009). The majority of all bionic structures used in industrial applications are sandwich components with honeycomb cores. These structures are particularly used in aerospace and the automotive industry, because in these branches, there is a special need on light and highly load parts. (Kerz 1988)

2. State of the art

Sandwich components are part of composite design strategies und provide a high potential for combining all three lightweight design approaches, which are listed in chapter 1. Sandwich parts can be used for mechanical, thermal or acoustic problems. Sandwich structures mostly consisted of three parts (Klein 2009):

- Face sheets
- Core
- Adhesive bonds

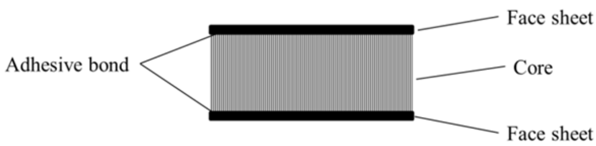

Fig. 1. Sandwich part (schematic).

Materials used for the face sheets mostly offer a high Young`s modulus, like fiber-reinforced plastics or steel and aluminum compositions. Cores in sandwich structures can be designed as homogeneous material, like foams or paper filling, or as textured cores, such as honeycombs. Homogeneous cores are used mainly in low-cost and low-stressed parts. Otherwise textural cores (e. g. honeycombs) can be found in parts with the highest requirements related to mass and stiffness. (Heimbs 2008; Wiedemann 1996; Klein; Torsakal 2007)

Currently, honeycomb cores are used in plane sandwich parts. There are possibilities for adapting honeycombs on freeform surfaces e. g. by using NOMEX® honeycombs, which means an aramid paper coated with phenol resin (see figure 2).

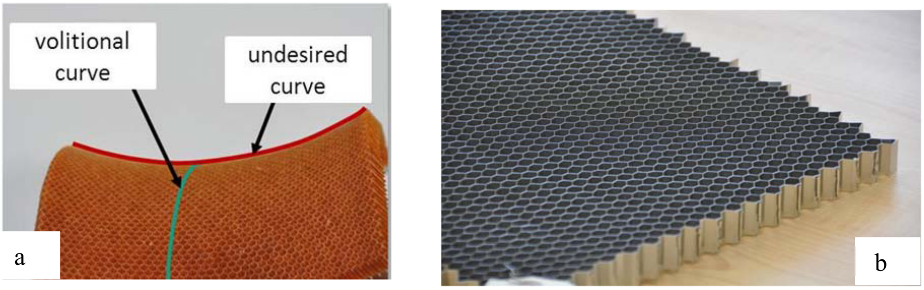

Fig. 2. (a) NOMEX® honeycomb adapted to a complex free-form surface; (b) Conventionally manufactured honeycomb structure.

As a result of adapting NOMEX® honeycombs on curved surfaces, the so called saddle-effect occurs: The green line in figure 2a is the volitional curve for adapting a honeycomb structure on a freeform surface. The red line is the undesired curve. For this reason there are lots of steps necessary, for example warming the honeycombs or cutting the structure into pieces, in order to adapt it to the surface. In using conventional manufacturing technologies, honeycombs can nowadays only be produced with a regular texture like uniform wall thicknesses and honeycomb diameters (see figure 2b). No adaptation to a complex curved surface or the variation of the material filling degree load-oriented adjustment is possible.

3. Objective of the paper

For the purpose of a load-dependent optimization and free-form sandwich structures, a manufacturing process with a high geometric flexibility is required. Additive manufacturing (AM) offers a great potential for lightweight design, because of the layer wise build-up process and the achievable geometry flexibility in contrast to the conventional manufacturing methods (Gibson ET AL.2010; Reinhart et al. 2013). Additive layer manufacturing offers the possibility to adapt honeycomb structures on a freeform surface without further deformation processes. In addition, sandwich cores can be adapted to the load by varying the material filling degree, the wall thickness and the honeycomb diameter.

Furthermore, the integration of additional functional parts like inserts for load transmission, lattice structures for eliminating the telegraphing effect, as well as snap-in components for building large-volume sandwich components can be realized. The telegraphing effect is a result of the integral building technique. That means, the face sheets are placed directly on the honeycomb core by a wet lay-up process. Afterwards, the sandwich part is cured in the autoclave. If there are unadventurous ratios between the thicknesses of the fiber reinforced plastics face sheets and the honeycomb diameters, the face sheets are dipping into the honeycomb surface because of the pressure of the autoclave (see figure 3, Flemming et al. 1996).

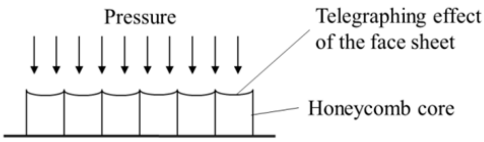

Fig. 3. Telegraphing effect (schematic).

The main objective of this paper is to show the potential of load-dependent optimized honeycomb structures for sandwich panels by means of cost, production time and quality in using additive layer manufacturing. For this purpose, a novel design approach has been explored, which allows a better exploitation of the lightweight potential of sandwich components with honeycombs by varying the wall thicknesses and honeycomb diameter and integrating additional functions.

4. Approach

First of all, the boundary conditions and requirements must be defined and included. For example, design-rules for additive manufacturing have to be taken into account, such as the geometrical limitations like minimum wall thickness, the minimum honeycomb diameter and the mechanical properties of honeycomb structures. For this purpose, a proprietary method has been developed, which focusses on the challenges of thin-walled, anisotropic and additively fabricated structures. By using non-proportional, flat tensile specimens, the mechanical properties, which are essential for load-dependent honeycomb structures, were recorded. The procedure for designing three dimensional and load-dependent sandwich components is shown in figure 4.

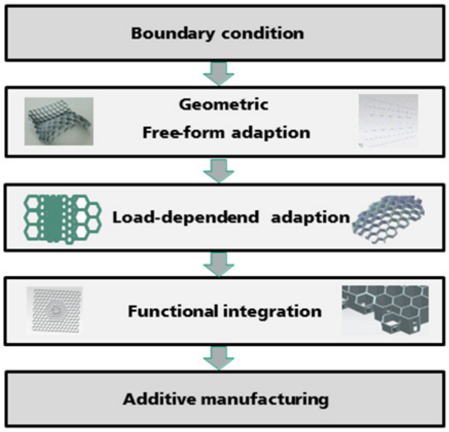

Fig. 4. Procedure for the design of three dimensional, load-dependent sandwich components.

4.1. Free-form surface adaption

Initially, the honeycomb structure is adapted to a free-form surface. It should be ensured that the face sheets of the sandwich part are parallel to each other. The free-form adaption can be done by three different approaches: First, a free-form surface adaption can be done by using ISO-parametric curves (see Figure 5). This means, that the coordinate system is not plane, but it is curved along the free-form surface. The intersections of the ISO-parametric lines are defining the corners of the hexagonal sketch.

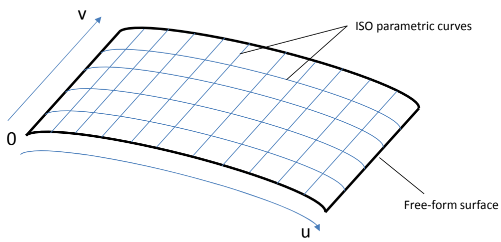

Fig. 5. ISO-parametric curves (mesh)

Secondly, a hexagonal structure in the middle of the free-form surface is created (see Figure 6). The center of this honeycomb is also the center of a circle with the desired diameter of the honeycomb. The intersection point of the circle and the free-form surface is the center of a new honeycomb structure.

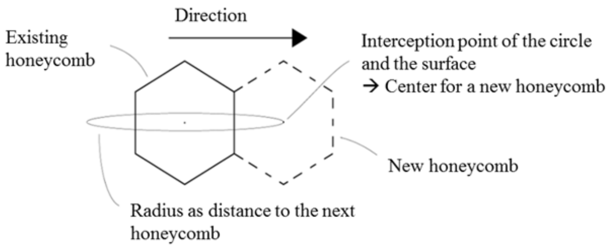

Fig. 6: Circle-hexagon-approach

The subsequent extrusion of the individual sketches is performed along the normal vectors of the honeycomb walls, so that each honeycomb wall is perpendicular to the free-form surface. This ensures that no or only low bending stresses is acting on the structure.

4.2. Load-dependent design

The load-dependent adaptation of the honeycombs is done by varying the density of the structure. Parameters for this design optimization are the honeycomb wall thickness and the honeycomb diameter. The approach (see figure 7) is based on the Finite-Elements-Method (FEM). Initially, the reference stress for the load-dependent optimization must be defined and the simulation model must be prepared by defining bearings conditions, constraints and loads.

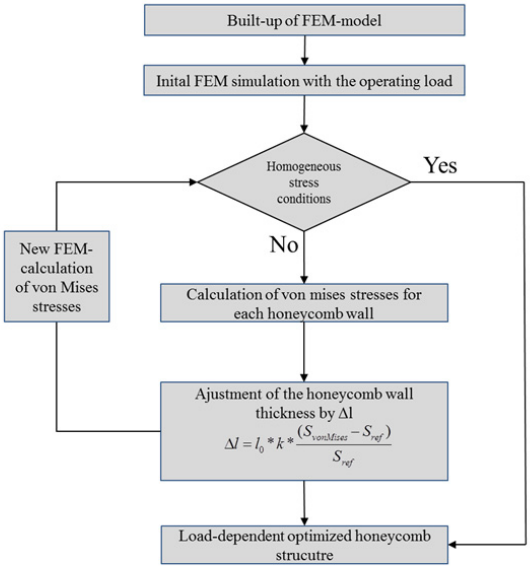

Fig. 7. Approach of load-dependent optimization of honeycombs.

The next step of this approach is the initial calculation of the von Mises stresses with the operating load, to identify highly loaded areas. If there is a homogeneous stress distribution, the load-dependent design is already done. If not, the next step is the determination of all von Mises stresses inside the honeycomb structure and the identification of the arithmetic mean stress of each wall. The following adjustment of the wall thickness difference Δl as a function of the identified comparison stresses $\delta_{vonMises}$ is done by an approach according to the CAO-methodology by Mattheck (2006).

The calculation of wall the thickness variation Δl is shown in equation (1) with l_0 as the initial wall thickness, $\delta_{vonMises}$ as the calculated, arithmetic mean of the comparison stress of each honeycomb wall, $\delta_{vonMises}$ as the reference or target stress and finally k as an advantage factor.

$$\Delta l = l_0 * k * \frac{(S_{vonMises} - S_{ref})}{S_{ref}} \tag{1}$$

Figure 8a shows the honeycomb walls after the initial calculation in three different colors. The red walls are overloaded, which means the walls must be thicker (Δl > 0). The yellow colored walls are derated, so the wall thickness can be reduced (Δl < 0). Finally, the green honeycomb walls are load-dependent designed. Thus, areas that are highly loaded have honeycombs with greater wall thicknesses, and areas with lower loads have thin-walled honeycomb cells (see Figure 8b).

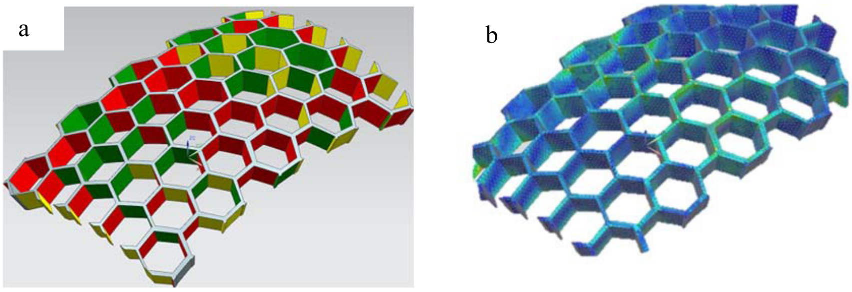

Fig. 8. (a) stress distributions after the initial calculation; (b) part with varying honeycomb walls.

The transition from low to high stress areas are leading to a graded honeycomb structure. Thus, the entire geometry results in a homogeneous stress distribution.

4.3. Integration of Functions

The final step is the integration of functional components in the honeycomb structure. That means, inserts such as screw threads, which gather the external loads, are integrated directly into the core. So, there is no need for an extra process in order to integrate inserts.

Furthermore, hexagonal lattice structures are applied on the surface of the honeycomb core (see figure 9a). These structures are minimizing the telegraphing effect (see chapter 3). If there is a respective proportion between the honeycomb diameters and the carbon fiber reinforced plastic face, this anti-telegraphing solution is necessary (Funke 2001).

Parts built-up by using additive manufacturing are actually constraint in their component size. That means, the presented design approach can only be used for a small part volume such as 500x400x300 mm^3. For applying this design approach on parts with larger sizes, a methodology for splitting the parts is necessary. Therefor snap-in connections are added in the honeycomb structure (see figure 9b). Requirements to these connections are removability and stiffness against shearing strains. Thus, the design approaches can be applied for large-volume parts.

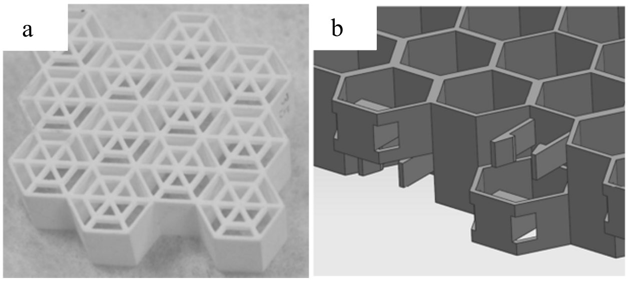

Fig. 9. (a) anti-telegraphing solution; (b) honeycomb structures with snap-in connections.

4.4. Application of the approach on the example of an interior component for automotive industry

Figure 10 shows, how the method can be applied to a demonstrator component. Firstly, every honeycomb cell was adapted conform to the surface of the part (Nguyen et al. 2012; Engelbrecht ET AL.2009). Secondly, the structure is optimized for lightweight design. Achieving a homogeneous stress distribution in the part is possible by varying the wall thickness, honeycomb diameter and amount of honeycomb cells depending on subjected stresses and strains. Thirdly, the integration of functional components (here screw threads) is done directly into the honeycomb core.

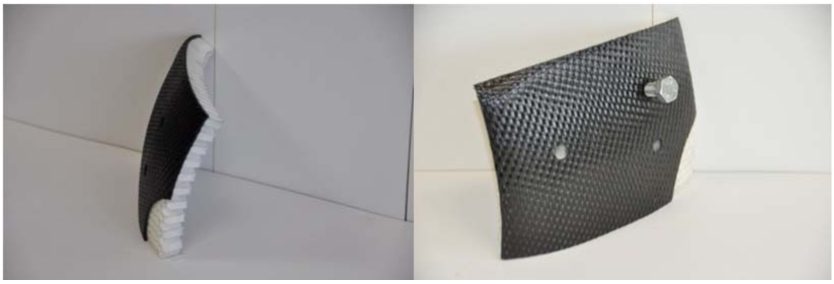

Fig. 10. Application of the approach on the example of an interior component for automotive industry.

5. Conclusion and outlook

The use of bionic lightweight approaches provides product developers with new ways for the design more resource-efficient and innovative components. Due to the manufacturing specified design for conventional manufacturing techniques, the weight reduction potential cannot be exploited fully. This can be demonstrated clearly on the example of honeycomb structures. Conventionally produced honeycomb structures cannot be adjusted only at great expense to free-form surfaces. Furthermore, there is no way load-dependent optimization, as well as for functional integration. One solution for this is the use of additive manufacturing.

The presented method for the load-dependent optimization and adaptation of honeycomb structures to a freeform surface, in combination with additive manufacturing provides the opportunity to make better use of the lightweight potential, compared to conventional production technologies.

In future works a technical and economic evaluation of this approach will be executed. As evaluation criterias, the production costs and time will be used in comparison to conventionally manufactured components. Based on the results, further research for the optimization of the individual blocks of the method will be performed.

Acknowledgements

We want to express our gratitude to the state government of Bavaria for its financial support in the build-up of the Fraunhofer Project Group for Resource-Efficient Mechatronic Processing Machines (RMV). Thereby, the research work on the topic presented in this paper was made possible.

References

BITZER 1997
Bitzer, T.: Honeycomb technology. 1 Aufl. London, New York: Chapman & Hall 1997. ISBN: 978-0-412-54050-9.

DEGISCHER ET AL. 2009
Degischer, H.-P.; Lüftl, S.: Leichtbau. Weinheim: Wiley-VCH 2009. ISBN: 978-3-527-32372-2.

ENGELBRECHT ET AL.2009
ENGELBRECHT, S.; FOLGAR, L.; ROSEN, D. W.; SCHULBERGER, G.; WILLIAMS, J.: CELLULAR STRUCTURES FOR OPTIMAL PERFORMANCE, SFF 2009

FLEMMING ET AL.1996
Flemming, M.; Ziegmann, G.; Roth, S.: Faserverbundbauweisen – Halbzeuge und Bauweisen, Springer Verlag Berlin Heidelberg (1996). ISBN: 3-540-60616-5

FUNKE 2001
Funke, H.: Systematische Entwicklung von Ultra-Leichtbaukonstruktionen in Faserverbund-Wabensandwichbauweise am Beispiel eines Kleinflugzeuges. Zugl. Diss. Universität-Gesamthochschule Paderborn (2001). Paderborn (2001).

GIBSON ET AL.2010
Gibson, I.; Rosen, D. W.; Stucker, B.: Additive manufacturing technologies, Springer Verlag New York (2010). ISBN: 978-1-4419-1119-3

HEIMBS 2008
Heimbs, S.: Sandwichstrukturen mit Wabenkern. Zugl. Diss. Technische Universität Kaiserslautern (2008)Techn. Univ. Kaiserslautern, Kaiserslautern (2008).

HENNING ET AL. 2011
Henning, F.; Moeller, E.: Handbuch Leichtbau. München: Hanser 2011. ISBN: 978-3-446-42891-1.

KERZ 1988
Kerz, P.: Natürliche und technische Konstruktionen in Sandwichbauweise. Konstruktion 40 (1988) nicht angegeben, S. 41–47.

KIEF ET AL. 2011
Kief, H. B.; Roschiwal, H. A.: CNC-Handbuch 2011/12. München: Hanser 2011. ISBN: 978-3446425941.

KLEIN 2009
Klein, B.: Leichtbau-Konstruktion. 8 Aufl. Wiesbaden: Vieweg + Teubner 2009. ISBN: 3834899658. (Studium).

LÖFFLER 2009
Löffler, S.: Anwenden bionischer Konstruktionsprinzipe in der Produktentwicklung. Zugl. Diss. Technische Universität Carola-Wilhemina zu Braunschweig (2008). Berlin: Logos-Verl. 2009. ISBN: 978-3-8325-2154-7. (Bericht // Institut für Konstruktionstechnik, Technische Universität Braunschweig 73).

MATTHECK 2006
Mattheck, C.: Design in der Natur. Der Baum als Lehrmeister. 4. Aufl. Freiburg i. Br. [u.a]: Rombarch 2006. ISBN: 3793-094707.

NGUYEN ET AL. 2012
Nguyen, J.; Park, SI.; Rosen, D. W.; Folgar, L.; Williams, J.: Conformal Lattice Structure Design and Fabrication, SFF (2012)

PRODBREGAR 2002
Prodbregar, N.: Bionik. <http://www.scinexx.de/inc/artikel_drucken_komplett.php?f_id=61&a_flag=2> - 06.04.2013.

REINHART ET AL. 2011
Reinhart, G.; Teufelhart, S.: Load-Adapted Design of Generative Manufactured Lattice Structures. Lasers in Manufacturing 2011 - Proceedings of the Sixth International WLT Conference on Lasers in Manufacturing 12 (2011) 0, S. 385–392.

REINHART ET AL. 2013
Reinhart, G.; Teufelhart, S.; Riß, F.: Auslegung von Gitter- und Wabenstrukturen für die additive Fertigung. lightwight design (2013) 1/2013, S. 24–28.

TORSAKUL 2007

Torsakul, S.: Modellierung und Simulation eines Verbunds von Sandwichplatten zur Entwicklung einer mechanischen Verbindungstechnik2007.

WIEDEMANN 1996
Wiedemann, J.: Leichtbau: Elemente. 2 Aufl. Berlin: Springer 1996. ISBN: 978-3-540-60746-5. (Leichtbau 1).